DEVELOPMENT OF FLOOD INUNDATION MAPS AND EMERGENCY ACTION PLAN FOR KRISHNA RIVER UPSTREAM OF ALMATTI RESERVOIR

by

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EXECUTIVE SUMMARY

Floods have been a recurrent phenomenon which brings devastation to settlements, misery to human lives and losses to infrastructure and public utilities. Historically, the upper Krishna basin has experienced the flood situation earlier several times also. However, in the recent time, the flood events have become a frequent phenomenon causing displacement chaotically, loss of life and property . Most severe was the one which happened during the month of July and August 2019 in Maharashtra & Karnataka state. Record highest quantity of water flowed in the River stream in the past century. Phenomenally a high number of population around 8.5 lakhs had to be moved to a safe place.

The Govt. of India, in its recent dam safety act of 2019, it mandates to develop the Emergency Action Plan (EAP). Also, the Central Water Commission (CWC) has initiated a project to delineate the flood inundation map of all the rivers in the country. However, it becomes necessary to develop EAP for the areas which are prone for the frequent floods.

In view of the floods of 2019 and its devastation caused in Karnataka State, the Inspector General of Police (IGP), Northern Range, Belagavi, Raghavendra Suhasaa collated the data from multiple sources in real time associated with the flood evolution spreadth and manifestation. Applied the sciences of Quantum Computing and did Predictive Analysis for the evacuation of the 8.5 lakhs people And this was further improved by developing the flood inundation map and the EAP with the National Institute of Hydrology, Belagavi. Accordingly, this study was initiated with the observed data of the IGP, Belagavi on day-to-day basis in real time. The study was carried out for two scenarios, i.e., for highest flow of 480,000 cusec and another for 200,000 cusecs. Also, the Ghataprabha river was also included in the study with highest flow of 214742 cusec.

The developed maps for Krishna River indicates that, the highest depth of flood water is 8.5 m and indicates 128 number of villages would be inundated for 480,000 cusec. Similarly, 8.5m and 96 villages for 200,000 cusec. Also, 6.5m water depth and 98 villages in the Ghataprabha river stretch also.

The developed maps for flood depth and flood arrival time would help the Police , administrators and public for developing the evacuation plan for minimizing the loss of life and property in the flood affected areas of River Krishna and River Ghataprabha in Karnataka state. The developed data and the inundation maps are also made part of the book Beyond Red Alert – Saving lives and distributed to the people across this Karnataka Krishna River Flood region for a purpose of awareness and survival during the crisis situation.

1 INTRODUCTION

Natural hazards have caused significant damages to natural and manmade environments during the last few decades. Hydro-meteorological hazards are among the most destructive hazards and are considered responsible for the loss of human lives, infrastructure damages and economic losses. Nowadays, there is a rising global awareness for hydrological hazard's impacts mitigation due to the increase in frequency, magnitude, and intensity of extreme events. The occurrence of hydrological and hydro-meteorological extremes (i.e., storms, floods and hydrological droughts) has always been a threat to human society. The observed increase in weather and hydro-climatological extremes, particularly in the last decades, has brought much-needed attention to the subject.

Recent analyses of a broad spectrum of water cycle variables, including precipitation, snow cover, floods and droughts, show that climate change is already affecting hydrology—and some of these changes have been unexpected. Conventional wisdom, in the form of global climate models and the basic laws of physics, predicts that the hydrologic cycle will accelerate as climate warms. Changing patterns of precipitation could potentially lead to more extreme floods and droughts.

For a developing country such as India, climate change in conjunction with other changes, such as rapid urbanization, deforestation, population explosion and industrial growth, has serious implications for policy and infrastructural growth in the water and related sectors. The impacts of climate change and climate variability will be felt mainly through water related issues, such as water scarcity, increase in demands and increase in frequencies of floods and droughts (Mondal & Mujumdar, 2015). According to Inter-governmental Panel on Climate Change (IPCC, 2010), it is important to capture signals of climate change at regional scale to understand how it influence the hydrologic changes in terms of modifications in water availability, frequent hydrologic extremes like floods and droughts, changes in water quality, changes in agricultural water demand, and other related phenomena.

The river Krishna being 4th largest river basin in India and has been the life line four states namely, Maharashtra, Karnataka, Telangana and Andhra Pradesh. The river has been major source of Irrigation for the drought areas of these states. In addition to creating Irrigation facilities, the river has been the source of power generation for Maharashtra and Karnataka state. A morphological study carried out by Sudhir et al., (2019) identified that, the river stretch downstream of Sangli (where the slope become flatter from 1:5000 to 1:13000) including the Maharashtra and Karnataka state border. Further they reported that, the Dhudhganga and Panchaganga river stretches bordering Karnataka state are prone for floods. Historically, the river basin is experiencing the floods, according to National Rainfed Area Authority (2011), the major recorded flood events in the Krishna river basin occurred in 1903, 1913, 2005, 2006 and 2009. However, in recent times, the frequently the upper Krishna basin is experiencing the flood with higher intensity. The most severe flood being the one experienced in 2019, wherein more than lakh people displaced with few casualties and a vast agriculture land was destroyed. This has inflicted huge economic loss to the resident of the town and villages on either side of the river Krishna, Dudhganga and Ghataprabha. Therefore, it is high time to devise a plan for minimizing the loss of life and property of the occupant of this area.

Keeping these incidences in mind, this is study is initiated with an objective of delineating the flood inundated areas for different flows and to assess the time required by the flood wave to reach various villages on the banks of River Krishan upstream of Almatti reservoir.

2 STUDY AREA

2.1 KRISHNA RIVER BASIN

The Krishna is the second largest river in Peninsular India. It rises in the Mahadev range of the Western Ghats near Mahabaleshwar at an altitude of 1336.55 m above sea level. Rising in the Ghats near the Arabian Sea, the Krishna flows through Maharashtra, Karnataka, Andhra Pradesh and Telangana States gathering water on its way from innumerable rivers, and drops into the Bay of Bengal. Location of the Krishna River basin on map of India is shown in Figure 2.1.

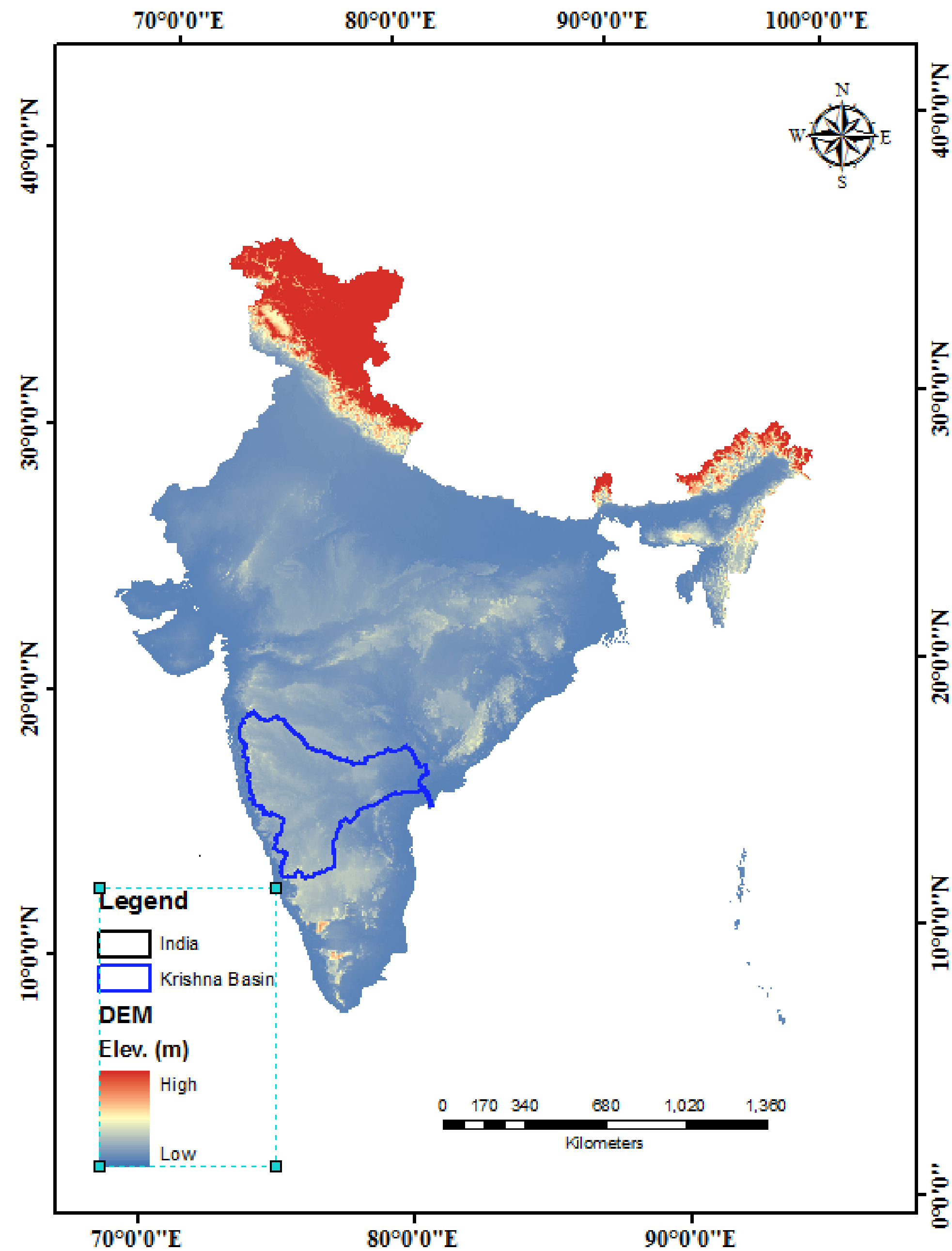


Figure 2.1: Location of the Krishna River basin on the map of India.

2.1.1 Location

The Krishna basin lies between latitudes 13° 7' to 19° 20' N and longitudes 73° 22' to 81° 10' E. It is roughly triangular in shape with its base along the Western Ghats and apex at Vijayawada. The basin extends over an area of 256293 sq. km which is nearly 8 per cent of the total geographical area of India. A map of Krishna River basin showing its coverage in various States and the location of various sub-basins is shown in Figure 2.2.

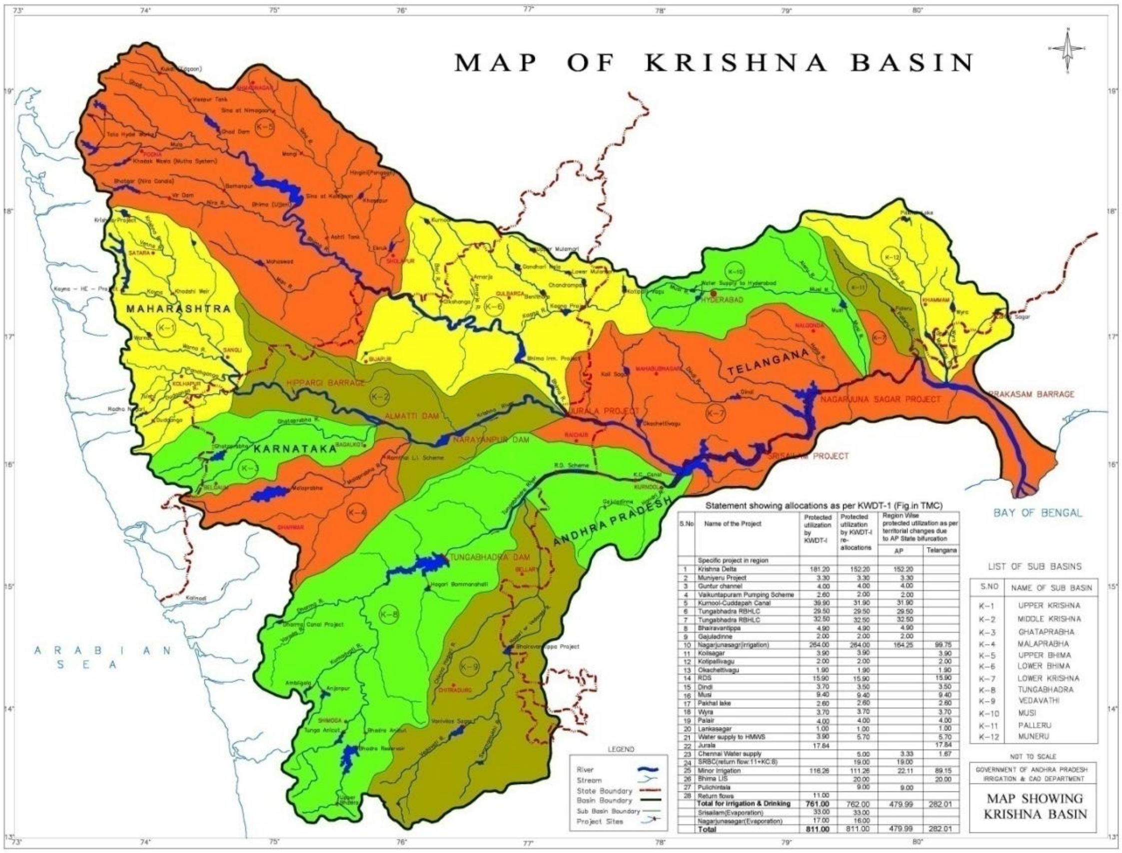


Figure 2.2: A map of Krishna River basin.

2.1.2 Topography, Elevation and Drainage

The western boundary of the basin is an almost unbroken line formed by the Western Ghats whose height ranges from 609 to 2133 m. This part of basin has the heaviest rainfall and the most humid climate. The Eastern Ghats, which form the eastern boundary of the peninsula, are not as well-defined and continuous as the Western Ghats. To the south of the Krishna, the Eastern Ghats comprise parallel ranges, which are the successive outcrops of an ancient series of stratified rocks.

The interior of the basin is a plateau divided into a series of valleys sloping generally towards the east. Belts of country adjoining the Western Ghats in the Upper Krishna, the Upper Bhima, the Ghataprabha, the Malaprabha and the Tungabhadra sub-basins are hilly and highly undulating and covered with dense and evergreen forests; the rest of these sub-basins are flatter and less undulating. Elevation range in various sub-basins is presented in Table 2.1.

Table 2.1: Elevation range in various sub-basins of Krishna River basin

Sub-basin ID	Name of sub-basin	Elevation from highest to lowest level (m)
	Upper Krishna sub-basin	
K-1	a) Western-Ghat area	1372 to 914
	b) Rest of area	914 to 610
K-2	**Middle Krishna sub-basin**	610 to 305
	Ghataprabha sub-basin	
K-3	a) Western-Ghat area	1372 to 914
	b) Rest of area	914 to 610
	Malaprabha sub-basin	
K-4	a) Western-Ghat area	914 to 610
	b) Rest of area	610 to 488

During the monsoon season, the Krishna occasionally swells into floods. The distinctive features of greater part of the river are low water level during dry weather, narrow and rocky bed and great flood lift, sometimes as much as 30.48 m. A drainage network map of Krishna basin is shown in Figure 2.3.

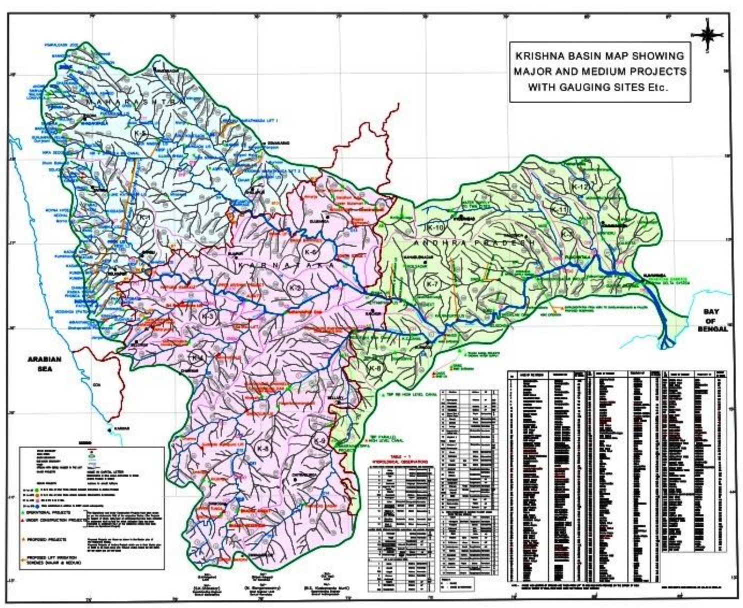


Figure 2.3: A map of Krishna River basin showing drainage network

2.1.3 Rainfall in the Krishna River basin

The heavy rainfall of the Western Ghats is the main source of supply of the Krishna river system. The Krishna basin drains a length of about 688.80 km of the Western Ghats, comprising 225 km in Upper

Krishna, 64 km in Ghataprabha, 32 km in Malaprabha, 160 km in Upper Bhima and 206 km in Tungabhadra sub-basins. The Western Ghats run almost parallel to the sea coast at a distance of 80 to 160 km from the sea. Precipitous on the western side, they fall away more gradually to the east. The heaviest rainfall occurs on the peak of the ridge, the intensity of the rainfall rapidly decreasing as we go eastwards. The rivers rise in the valleys close to the Ghats which divides the flow into two parts: the smaller portion falling westwards into the Arabian sea and the other flowing through rivers eastwards to the Bay of Bengal. Rainfall and its regional and seasonal distribution are the dominant natural factors that affect the life and economy of the people in Krishna basin. The basin in Karnataka and Maharashtra are influenced by the South-West Monsoon season and receives more than 90% of rainfall during this period.

2.1.4 Rainfall distribution and variability

Rainfall distribution in the basin is mainly influenced by the physical features of the terrain. The Western Ghats and a small belt of adjoining country of varying width receive the highest amount of rainfall. A large area to the east of the Western Ghats is a rain shadow region having rainfall below 600 mm. East of the rain shadow zone, the rainfall gradually rises and increases to about 1,050 mm.

The monthly seasonal and annual rainfall of the Krishna basin varies from year to year. The coefficient of variation (CV, an important statistical measure of variation = mean/Std. Dev.) of annual rainfall ranges from 20 to 35 %. For season June to September, the range is between 20 to over 40 %, for season October to December between 50 to about 100 %, and for season March to May between 50 to 100 %. In the eastern third of the basin, CV is between 20 to 30% during June to September. The monthly rainfall variation is generally higher than the seasonal variation. Low total rainfall and high variability go hand in hand.

Variability of rainfall creates the greatest drought hazards. Except in areas of abundant rainfall or assured irrigation, large deficiencies in the normal rainfall are likely to cause partial or complete failure of crops. Within the Krishna basin, there are insecure regions of low rainfall and large variability of rainfall where drought causing partial or complete crop failures and scarcity conditions prevail at frequent intervals.

2.2 AREA OF INTEREST FOR THE PRESENT STUDY

As described in the previous section, the Krishna River is divided into several sub-basins for a better yield estimates and water management. In the present study, the area upto Alamatti dam in Karnataka is considered. The upper catchment of Almatti, has been witnessing flooding situation over last decade or two. The flooding situation is happening in the upper Krishna basin consisting of K1, K2 and K3 sub-basin. These sub-basins basically cover the state of Karnataka and Maharashtra. The Karnataka state forms the lower catchment and receives the water from upstream catchment in Maharashtra, releases from the water resources project on river Krishna and its tributaries, in addition to the runoff generated in the state of Karnataka. A map showing the study area and location of water resources project is shown in Figure 2.4.

In upper Krishna basin of Maharashtra, number of major dams have constructed namely Dhom, Kanher, Urmodi, Tarli, Koyana, Warana, Radhanagari and Kallamwadi. Similarly, in Karnataka, Hidkal, and Almatti are major water storage projects in the study area are tabulated in Table .2 and in Figure 5.

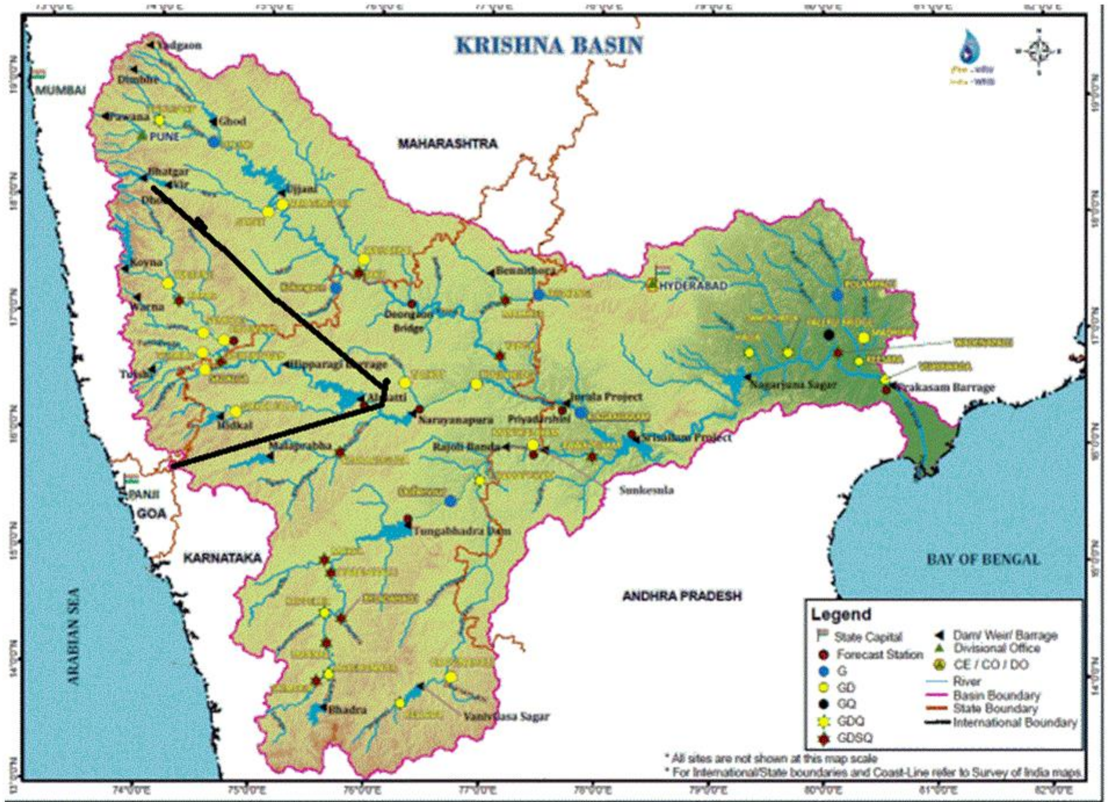


Figure 2.4: Showing the location of Major Water Resources Project in the Upper Krishna Project (Upstream of Almatti dam, encircle in Black thick line).

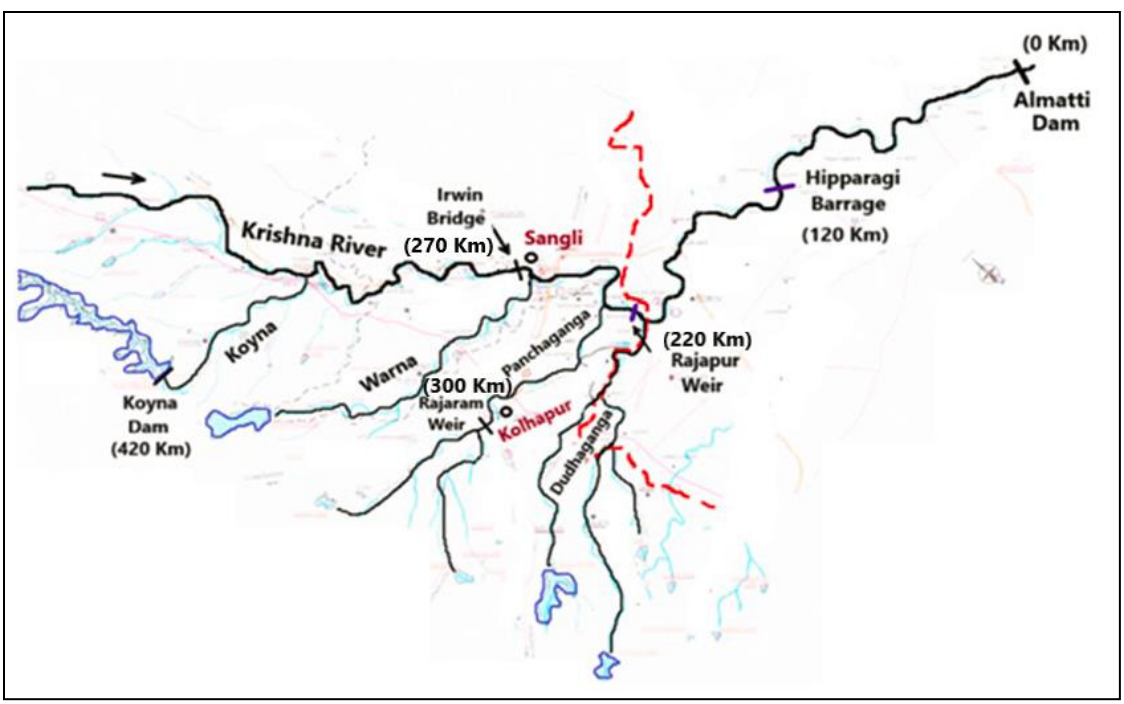


Figure 2.5: showing location of dams in Krishna basin upstream of Almatti reservoir.

Table 2.2: Important dams in Upper Krishna Basin upstream of Almatti reservoir (Source: Krishna Basin Profile by Central Water Commission).

Sl. No.	Name of dam	Name of the project	Location	Storage Capacity (MCM)	Year of Completion
1	Dhom Dam	Krishna Major Irrigation Project	Wai Satara Dist Maharashtra	331.050	1977
2	Ghataprabha Dam	Ghatprabha medium irrigation Project (Hydroelectric & Irrigation)	Kolhapur Dist Maharashtra	42.735	2009
3	Koyna Dam	Koyna Irrigation Project (Hydroelectric, Irrigation)	Satara Dist Maharashtra	2836.000	1964
4	Warna Dam	Warna Major Irrigation Project (Hydroelectric, Irrigation)	Kolhapur Dist	779.348	2000
5	Radhanagari Dam	Radhanagari Major Irrigation Project (Hydroelectric, Irrigation)	Kolhapur Dist	236.810	1938
6	Kallamwadi	Kallamwadi Major Irrigation Project (Hydroelectric, Irrigation)	Kolhapur Dist	719.120	1999
7	Kanher	Kanher Major Irrigation Project (Hydroelectric, Irrigation	Satara Dist	286.000	1986
8	Urmodi	Irrigation	Satara Dist		2001
9	Tarli	Irrigation	Satara Dist	165.700	2010
10	Hidkal Dam	Hidkal Major Irrigation Project (Hydroelectric, Irrigation	Belagavi Dist, Karnataka	1448.650	1977

2.2.1 Factors Influenced the Occurrence of Floods During July-Aug 2019

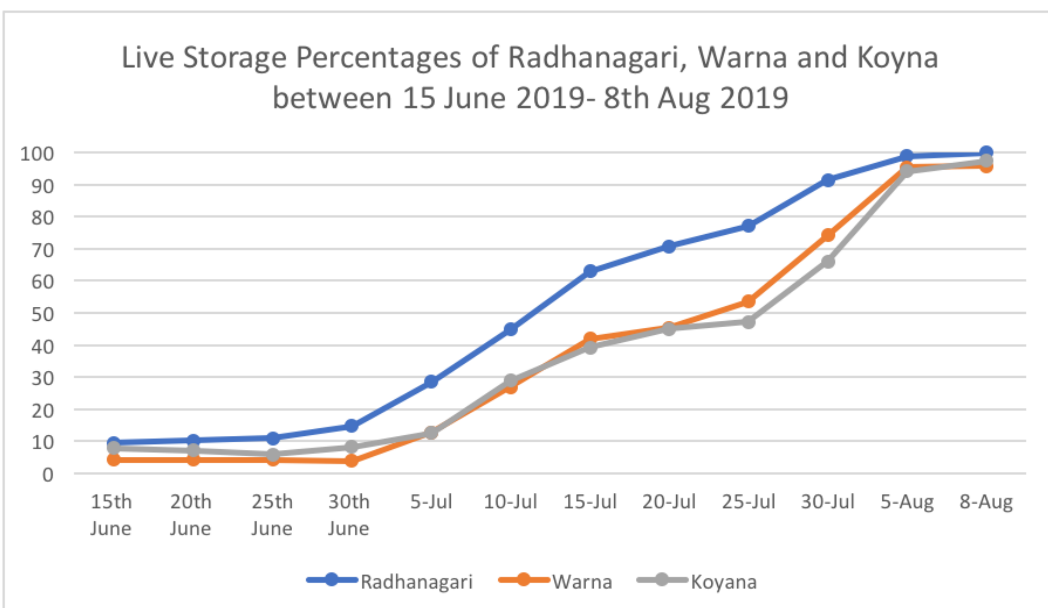
2.2.1.1 Meteorological Condition during the Flood Period.

Rainfall data indicates that Konkan and adjoining parts of Maharashtra experienced very heavy rainfall. In the beginning of the flood period i.e. from 27th Jul to 3rd Aug, the heavy rainfall events were

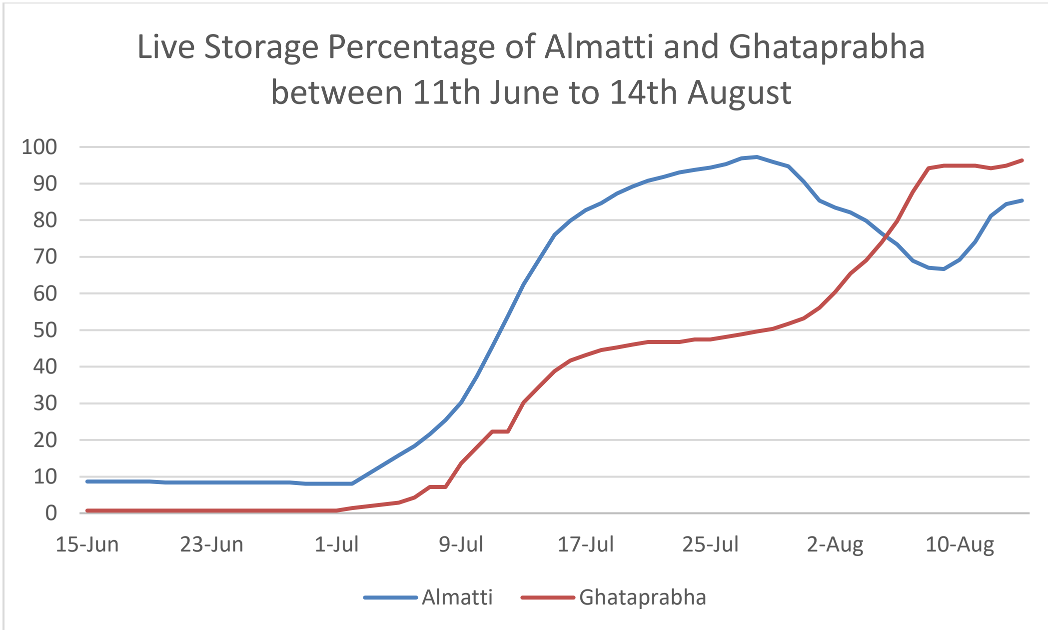
localized in the northern part of the Konkan. Towards the latter part of the week, rainfall at Mahabaleshwar recorded highest of 380 mm on 5th Aug. 2019. It is also observed that Kolhapur district continuously experienced heavy rainfall throughout the period with highest rainfall amounts on 6th Aug. 2019 (Patil et al 2020). It is further seen that during the heavy rain spell of Aug. 2019, many stations in Kolhapur district and western part of Satara district have crossed their previous record of 7 days rainfall. This indicates that compared to previous years, rainfall over the region was widespread and remained very intense for a long period during 27th July to 13th August 2019. Sangli, Kolhapur and Satara district received very heavy rainfall in comparison to 333 mm normal rainfall during 27th July to 13th August. Further, it is seen that the observed actual rainfall in various catchments to the upstream of dams varies from 5 to 19 times the normal. Average actual rainfall was about 6 times the normal rainfall in all these catchments bringing abnormal flood to downstream areas (Maharashtra State Expert Committee Report, 2019).

2.2.1.2 Hydrological Conditions

As stated earlier, there are 10 major dams located upstream of Almatti dam, which have different storage capacity as shown in Table 2.2. Due to the very high rainfall during the month of July and early August of 2019, the reservoirs in the catchment area were almost full in upper Krishna basin (Figure 2.6). At the same period, in downstream, the Hidkal dam (95%) and Almatti dam (80%) were maintaining a storage of greater than 80% of the gross storage (CWM Report). This situation was followed by another high rainfall event in the upper catchment, which eventually forced the dam operator to release very high quantity of water from each of the upstream reservoirs (Patil et al, 2020). Since the Almatti dam was 80% full extending its water spread area extending upto a distance of 120-130 kms. This huge quantum of water from river Krishna, river Dudhganga have entered the reservoir and started building up the water level due to back water effect causing the inundation of water adjoining the river. As reported by the Inspector General of Police (IGP) Northern Range, Belagavi, more than 80 village all along river Krishna upto backwater of Almatti have inundated (Raghavendra Suhas H G., 2020). In addition to this, the villages adjoining to Ghataprabha and Dudhganga river.



(a)



(b)

Figure 2.6: Live Storage (%) of reservoir during July and August 2019 in the state of (a) Maharashtra (b) Karnataka.

2.2.2 Problem Definition

As reported by many authors (Rupai & Majumadar.,2018, Nayak at al., 2019), have reported that, the frequency and intensity of floods will be increasing in the coming years in many of the large basins of India. They reasoned that, the climate change would be one of the main factors which will be influencing the floods. Krishna River being one of the large basins, which is expected, witnesses the floods in the catchment. As the river originates from the Western Ghats, which is expected to undergo a large variation in intensity and quantity of rainfall (Venkatesh et al., 2021).

Climate change vulnerability assessments are necessary for designing targeted adaptation actions. The vulnerability analysis was carried out for different sectors at various levels of governance, on the basis of Macro level Vulnerability Indices, estimated using the Indices of Exposure, Sensitivity and adoptive capacities to climate changes. This was done by the State Action Plan on Climate Change. However, it is very important to develop necessary action plan locally to prevent the loss of life, property and crops. In view of this, the Inspector General of Police (IGP), Northern Range Belagavi, approached National Institute of Hydrology, Belagavi to prepare the flood inundation maps to know the depth and arrival time so as to devise the necessary evacuation plan to minimize the loss of life, damage to the property and loss of crop. Keeping this in mind, this study initiated with the following objectives

1. Develop the flood inundation map for the stretch of River Krishna and its tributaries as they enter Karnataka state upto upstream of Almatti dam.
2. Developing EAP.

3 FLOOD INUNDATION MAPPING

3.1 INTRODUCTION

The construction of dams in rivers can provide considerable benefits such as the supply of drinking and irrigation water as well as the generation of electric power and flood protection; however, the consequences which would result in the event of their failure could be catastrophic. They vary dramatically depending on the extent of the inundation area, the size of the population at risk, and the amount of warning time available.

Dam break or excessive release of water from the dam may be summarized as the partial or catastrophic events. Such an event can have a major impact on the land and communities downstream of the structure. The excessive or uncontrolled releases may result in a high flood wave traveling along a valley at quite high speeds. The impact of such a wave on developed areas can be sufficient enough to destroy infrastructure, such as, roads, railways and bridges, and, to damage buildings. With such destructive force comes an inevitable loss of life, if advance warning and evacuation were not possible. Additional features of such extreme flooding include movement of large amounts of sediment (mud) and debris along with the risk of distributing pollutants from any sources, such as chemical works or mines in the flood risk area.

3.2 NEED FOR FLOOD INUNDATION MODELLING

The extreme nature of floods means that flow conditions will far exceed the magnitude of most natural flood events. Under these conditions, flow will behave differently to conditions assumed for normal river flow modelling and areas will be inundated, that are not normally considered. This makes dam break modelling a separate study for the risk management and emergency action plan.

The objective of such type modelling or flood routing is to simulate the movement of a dam break flood wave along a valley or indeed any area ‘downstream’ that would flood as a result of dam failure. The key information required at any point of interest within this flood zone is generally:

i. Time of first arrival of flood water
ii. Peak water level – extent of inundation
iii. Time of peak water level
iv. Depth and velocity of flood water (allowing estimation of damage potential)
v. Duration of flooding

The nature, accuracy and format of information produced from a dam break analysis will be influenced by the end application of the data.

In India, Risk assessment and disaster management plan has been made a mandatory requirement while submitting application for environmental clearance in respect of river valley projects. Preparation of Emergency Action Plan after detailed dam break study has become a major component of dam safety programme of India.

3.3 FLOOD INUNDATION MODELING

Generally, flood inundation modeling can be carried out by either i) scaled physical hydraulic models, or ii) mathematical simulation using computer. A modern tool to deal with this problem is the mathematical model, which is most cost effective and reasonably solves the governing flow equations of continuity and momentum by computer simulation.

Mathematical modeling of dam breach floods can be carried out by either one dimensional analysis or two-dimensional analysis. In one dimensional analysis, the information about the magnitude of flood, i.e., discharge and water levels, variation of these with time and velocity of flow through breach can be had in the direction of flow. In the case of two-dimensional analysis, the additional information about the inundated area, variation of surface elevation and velocities in two dimensions can also be assessed.

One dimensional analysis is generally accepted, when valley is long and narrow and the flood wave characteristics over a large distance from the dam are of main interest. On the other hand, when the valley widens considerably downstream of dam and large area is likely to be flooded, two-dimensional analysis is necessary. In the instant case, as the River Krishna valley is long and the flood wave characteristics over a large distance from the dam are of main interest, one dimensional modeling was adopted.

3.4 METHODOLOGY

3.4.1 HEC-RAS Hydraulics

3.4.1.1 Overview of the Model Theory and Hydraulics

One-dimensional models are based on the assumption that all discharge through any cross section is normal to that cross section at all locations. Obviously, this is not true for an actual river, but in many cases the assumption provides quite reasonable results if the cross sections are judiciously located and constructed. To best reflect this assumption, terrain cross sections for 1D models must be delineated such that flow is normal to the cross section. This often requires that cross sections have breaks with individual line segments perpendicular to the terrain contours. The hydraulic engineer must be able to visualize the flow patterns which are likely to occur and to draw the cross sections accordingly. This can be a challenging task and one whose difficulty greatly depends upon the complexity of the terrain. In the end, engineers must rely on their best judgment to properly model a reach.

3.4.1.2 One-Dimensional HEC-RAS Equations

During a steady-state simulation for HEC-RAS 1D, the flow profile is determined from one cross section to the next by solving the energy equation and by employing the standard step method (Figure 3.1).

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Where:

Z = channel invert elevation,

Y = water depth,

α = velocity-weighting coefficient,

V = average velocity for the cross-section,

g = gravitational acceleration, and

h_e = energy loss from Section 2 to 1

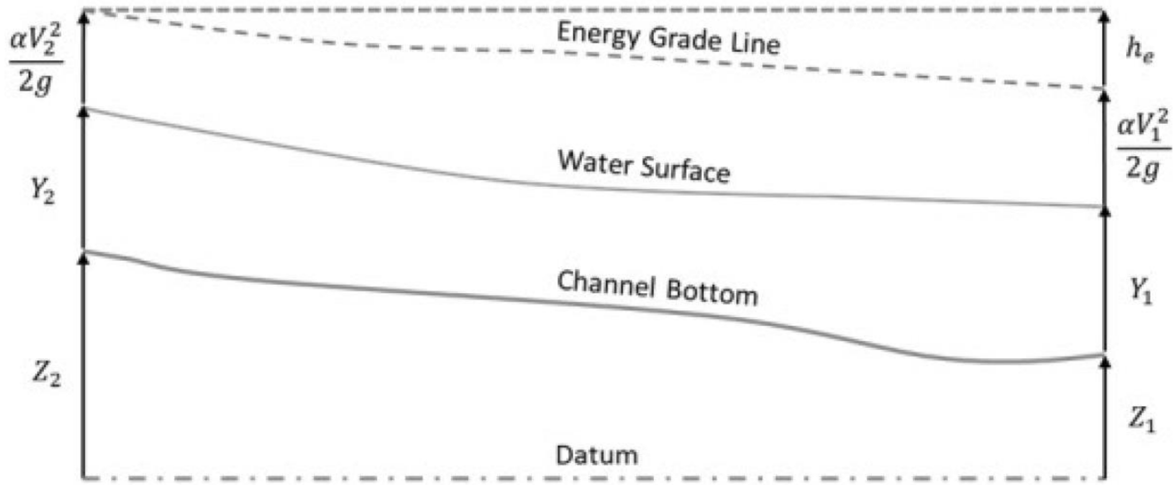


Figure 3.1: Diagram showing terms used in HEC-RAS 1D Energy Equation.

3.4.2 Downstream Flood Routing

Downstream routing of the flood wave is the most important and complex stage in the entire analysis. If downstream routing has wrong assumptions, the final result and derived conclusions would be poor, consequently the effort made towards estimating the breach parameters and routing the inflow hydrograph through the reservoir with the best methodologies in previous stages would have been in vain. That is why, is it is extremely important that the modeler truly understand how the software works, which equations are solved, and how the calculations are carried out.

HEC-RAS has several options for downstream flood routing, which involve a combined 1D/2DH analysis. However, here only the 2DH approach is described. The main advantage of HEC-RAS over other models at the moment is that all they reduce each cell to a single elevation, and each face to a single straight line, and this in itself could produce bad results

A modeler needs to ask how accurate could be the estimation of the channel shape, wetted perimeter, and volume underneath the computed water surface if only a few cells across the main channel are used, as with models that reduce each cell to a single elevation. This could produce a poor estimate of the hydraulic parameters mentioned before, and will definitely affect the results that the model produces.

Additionally, with these types of models, if you change the cell size, you will get different estimates of these parameters within the channel and floodplain, and consequently it is difficult to choose a consistent Manning´s value. This means that roughness coefficients selected for these models are tied to the grid resolution, and they will need to be changed when changing grid resolutions. HEC-RAS permits the grid resolution be changed and while still maintaining accurate estimates of the channel

and floodplain shape, wetted perimeter, and volume underneath the water surface. This reduces the necessity to have different Manning's roughness values for different grid resolutions.

Another important parameter besides the grid resolution (Δx) is the time step for computations (Δt). Because HEC-RAS uses a semi-implicit solution scheme for a non-conservative form of the full momentum equation, a modeler has more flexibility to use a wide range of time steps and still maintain the accuracy and stability of the numerical solution, which is synonymous of Courant numbers equal or less than 1.0. "Courant" number is defined as the dimensional number that satisfies the Courant–Friedrichs–Lewy (CFL) condition in numerical analysis, which establish that if a wave is moving across a discrete spatial grid (Δx) and we want to compute its amplitude at discrete time steps of equal duration (Δt), then this duration must be less than the time for the wave to travel to adjacent grid points. The Courant number (*Cr*) can then be written as

$$Cr = wave\ speed\ .\frac{\Delta t}{\Delta x} \leq 1.0$$

However, HEC-RAS can maintain this stability and accuracy even for Courant numbers higher than 1.0 (max 2.0). This last is not possible for models that use explicit solution schemes, where the use of time steps too large or Courant numbers greater than 1.0 will cause computational instabilities.

A good approach to get a first clue of which time step use in HEC-RAS is to find the downstream area where the largest velocities are expected (this could be accomplished running a first quick simulation, maybe in steady regime with the maximum flow, or starting the unsteady simulation with a first guess and making a better estimation later), then using the maximum value of these velocities as approximation of the wave speed, and using the average cell size of that area as "Δx" can be computed the time step "Δt" needed to obtain a Courant number equal to 1.0 as follows

$$\Delta t = \frac{\Delta x}{wave\ speed}$$

4 APPLICATION OF MODEL FOR THE STUDY AREA

As described in the Chapter 2, the study area and the objectives set for the analysis, the study area is restricted upto the upstream of Almatti dam from the entry point of River Krishna into the Karnataka State (Figure 2.5) along with Dudhganga river, which joins before the Kallola village. On the southern part of the study area, the Ghataprabha river downstream of Hidkal dam after the confluence of Markandeya river (downstream of Gokak) was included for developing the flood inundation maps.

The development of flood inundation map require data such as river discharge, the Digital Elevation Model (DEM), Toposheet, and details of hydraulic structure if any. In the present case, the river discharges were measured on River Krishna, River Dudhganga and River Ghataprabha. However, the flow data for Krishna River was available at couple of locations (Raghavendra Suhas H G., 2020). However, for the study purpose, the flow data at state boundary was considered for both River Krishna and River Dudhganga, and for River Ghatraprabha downstream of Gokak. The flow details during the flood period are tabulated in Table 4.1 and Table 4.2.

Table 4.1: Measured flows at various point on River Krishna and its tributaries during the flood season of 2019 (Raghavedra Suhas H G, 2020).

Measured the water flow on DD.MM.YY	Rajapura Weir (Interstate entry point of of Krishna river from Maharashtra to Karnataka) (Cusecs)	River Doodhganga (Kalamwadi Dam) + River Vedhganga (Patgaon Dam) inflow into Krishna Stream. (From Sadalaga And Kardaga Points) (Cusecs)	Kallola Barrage (Measur-ement (Gauge) (Cusecs)	Hipparagi Barrage (Cusecs)	Almatti Dam Inflow (Cusecs)	Almatti Dam Outflow (Cusecs)
31.07.19	149625	25520	175145	121500	119850	175563
01.08.19	160195	29920	190114	182400	150409	212753
02.08.19	163975	32032	196007	218500	205832	229292
03.08.19	172030	33088	205118	228100	222113	238573
04.08.19	196623	34496	23119	245000	233190	258710
05.08.19	227068	37312	264380	264000	259000	303525
06.08.19	252582	42240	294825	283000	318000	320535
07.08.19	295890	50572	346362	316000	364939	362875
08.08.19	334000	57024	388970	354000	385340	355340
09.09.19	338000	60896	391896	401000	430000 (12.30PM)	380000
10.08.19	344000	63360	407360	422000	570000 (8 PM)	530000
					600833 (2 PM)	
				458000	631475 (5 PM)	
11.08.19	344000	63120	410000	494000	680272	530000

					(6 PM)	
				508000	645556 (8.30 PM)	
				515000	606944 (12PM)	
					616944 (6 PM)	
12.08.19	321383	63000	418680	523000	641990	540000
13.08.19	288000	55440	343440	433000	611667	570000
					597778 (1PM)	
					611790 (3PM)	
					604814 (6PM)	
14.08.19	237187	50840	288027	424000	587754	570000
					568252	
				414000	545397	
15.08.19	187807	45056	226251	405000	523583	550000
				391000	473581	
16.08.19	153000	38720	191720	375000	479563	520000
				363000	438333	
17.08.19	128500	31680	160180	329000	447129	420000
18.08.19	83512	23232	106744	280000	341759	300000
19.08.19	53400	10653	64053	182000	215000	215000
20.08.19	32700	7040	39740	80000	111250	100000
21.08.19	29196		34828	25000	45064	
22.08.19	23100		27852	25000	20551	

Table 4.2: Measured flows at various point on River Ghataprabha and its tributaries during the flood season of 2019 (Raghavedra Suhas H G, 2020).

Measured the water flow on DD.MM.YY	Markandeya (enters in right side of Ghataprabha river) (CUSECS)	Bellary Naala (enters in right side of Ghataprabha river) (CUSECS)	Hiranyakeshi (enters in left side of Ghataprabha river) (CUSECS)	Ghataprabha River (Hidkal Dam Water Discharge) (CUSECS)	Ghataprabha River (CUSECS)
31.07.19	5000	12000	10000	2620	29620
01.08.19	5000	13000	14500	2474	35000
02.08.19	12500	15000	16500	2425	46425
03.08.19	14000	18000	17000	2328	51328
04.08.19	16500	18500	20500	2413	57913
05.08.19	18000	19000	23000	44038	104038

06.08.19	23000	20000	27000	58000	128040
07.08.19	27000	21000	38000	89134	175134
08.08.19	38500	24100	50200	97460	210260
09.09.19	38800	24000	51000	100942	214742
10.08.19	24600	19500	48000	108751	200851
11.08.19	8455	15256	41102	90617	155430
12.08.19	7000	11500	39000	85003	142503
13.08.19	3400	9760	18718	47599	79477
14.08.19	3400	8000	15000	42145	68545
15.08.19	3000	7000	13500	34168	57668
16.08.19	2700	6000	12700	29000	50400
17.08.19	2500	5000	11500	24564	43564
18.08.19				11266	
19.08.19				5000	
20.08.19				8535	
21.08.19				5201	
22.08.19				5330	

4.1 Digital Elevation Model (DEM)

The flood mapping using the HEC-RAS requires the river cross-sections of the selected reach of the river for the analysis. However, the HEC-RAS 2D requires the DEM for the purpose. Therefore, we are using HEC-RAS 2D for the study. The required DEM was downloaded from ALOS PALSAR – Radiometric Terrain Correction which provides the DEM with 12.5 m resolution. The entire area which is selected for analysis covers number of tiles (7 tiles). The complete DEM used for the analysis is shown in Figure 4.1 The elevation of the area varies between 93m to 953m with a gentle slope category of around 3% (30 m/Km). As it is seen that, the study area it is more of flat land have a very gentle slope. However, there are few intermittent hillocks in the study area.

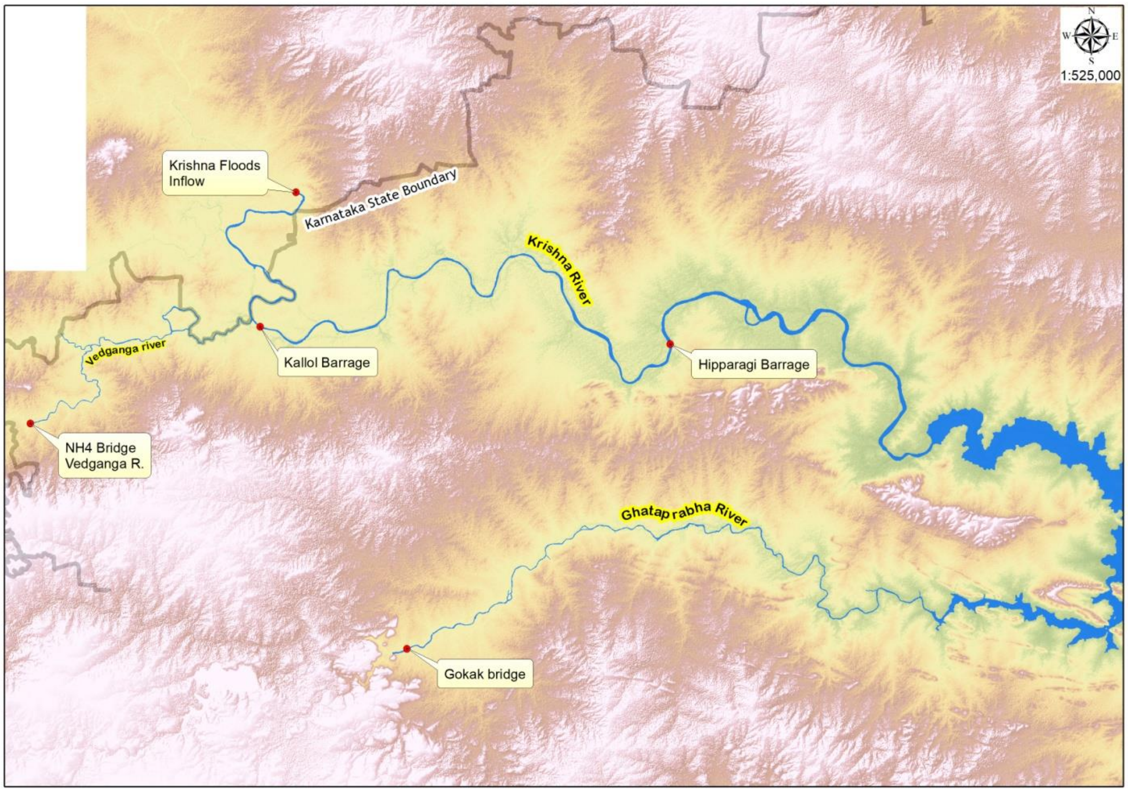


Figure 4.1: Map showing the elevation with location of the flow measurements and the boundary condition in the model.

4.2 CREATION OF 2D FLOW AREA

The 2D flow area is the region of a model in which the flow through that region will be computed with the HEC-RAS. In the resent study, the flow area is drawn to cover the area downstream of State boundary upto the upstream of Almatti reservoir. which would get inundated due to the failure of the dam as shown in Figure 4.2. There are 213957 cells of size 250m X 250m covering the area. The average area of the cell is 62719 m^2. The 2D flow is located at just state boundary and upto the upstream of Almatti reservoir.

Figure 4.2: The storage area marked down stream of Karnataka State.

4.3 Boundary Conditions (BC)

The assumptions concerning BC are well essential used for modeling. As we use the boundary conditions to define the conditions are to be used in the study. There are two types of boundary condition, i.e., on upstream and downstream. The upstream boundary conditions are basically used for defining the flow conditions and on the downstream, we use to define the conditions as observed in the field.

In the present study, there are 4 upstream boundary conditions define the flow conditions, i.e., flow in River Krishna, River Dudhganga, upstream of Hipparagi barrage and River Ghataprabha. On the downstream, the FRL of the Almatti reservoir has been defined at 2 points where river Krishna and river Ghataraprabha entering the reservoir. The boundary condition and their locations are shown in Figure 10. The flow data at upstream boundary conditions were given on hourly basis for a period of days it is observed as shown in Table 4.1 and Table 4.2. The base period used for the flow data is 72 hours. The flow data used for the simulation are tabulated in Table 4.3 and Table 4.4.

The two scenarios were used as the boundary conditions, such as minimum flow which can cause the flood inundation and the maximum observed flow which has caused the devastation in the study area.

Table 4.3: Scenario – I for floods near to 2lacs cusecs

Dates of Flow Measurement	Rajapur weir (Cusecs)	Dhudganga River (Cusecs)	Hipparagi Barrage (Cusecs)
2-Aug	1,63,975	32,032	22,493
3-Aug	1,72,030	33,088	22,982

Table 4.4: Scenario – II for floods near to 5lacs cusecs

Dates of Flow Measurement	Rajapur weir (Cusecs)	Dhudganga River (Cusecs)	Hipparagi Barrage (Cusecs)
11-Aug	3,34,000	63,120	96,880
12-Aug	3,21,383	63,000	1,38,617

4.4 FLOOD MAPPING

Unsteady flow simulation was carried out for the study. Hydrograph output interval taken as 15 minutes; computational interval taken 1 minutes for a period of 72 hrs. Here in this study, two flow conditions are used, i.e., high flow (4,80,000 cusec) and minimum flow which would result in the flood situation in the study area (2,00,000cusec). These flow conditions are used with aim to develop evacuation plan for the study area. The flow value considered for Ghataprabha was 2,14,742 cusecs in both cases.

The simulations were done for different flow conditions, the area of inundation due to the high discharge is shown in the Figure 4.3 and Figure 4.4. The Maximum depth of water and the arrival time is shown in Figure 4.3 and Figure. Also, Table 4.5, Table 4.6 and Table 4.7Table 4.5: depicts the arrival for peak flood and the depth at the selected location along the stream and its adjoining areas. There are nearly 224 settlements which are affected by Krishna and Ghataprabha Floods. The Flood Depth ranging up to maximum of 8.5m.

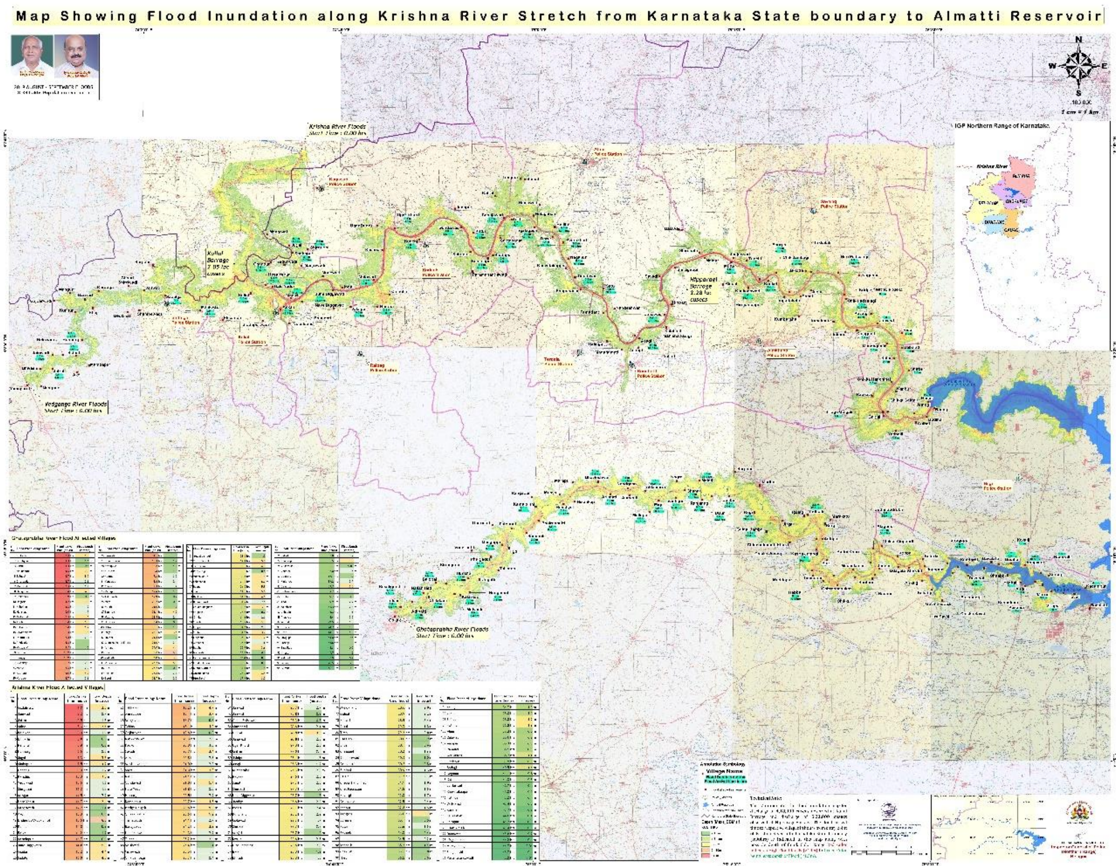


Figure 4.3: Flood Inundation Map for Krishna Floods during August 2019 for floods near to 5lacs cusecs (Scenario-II)

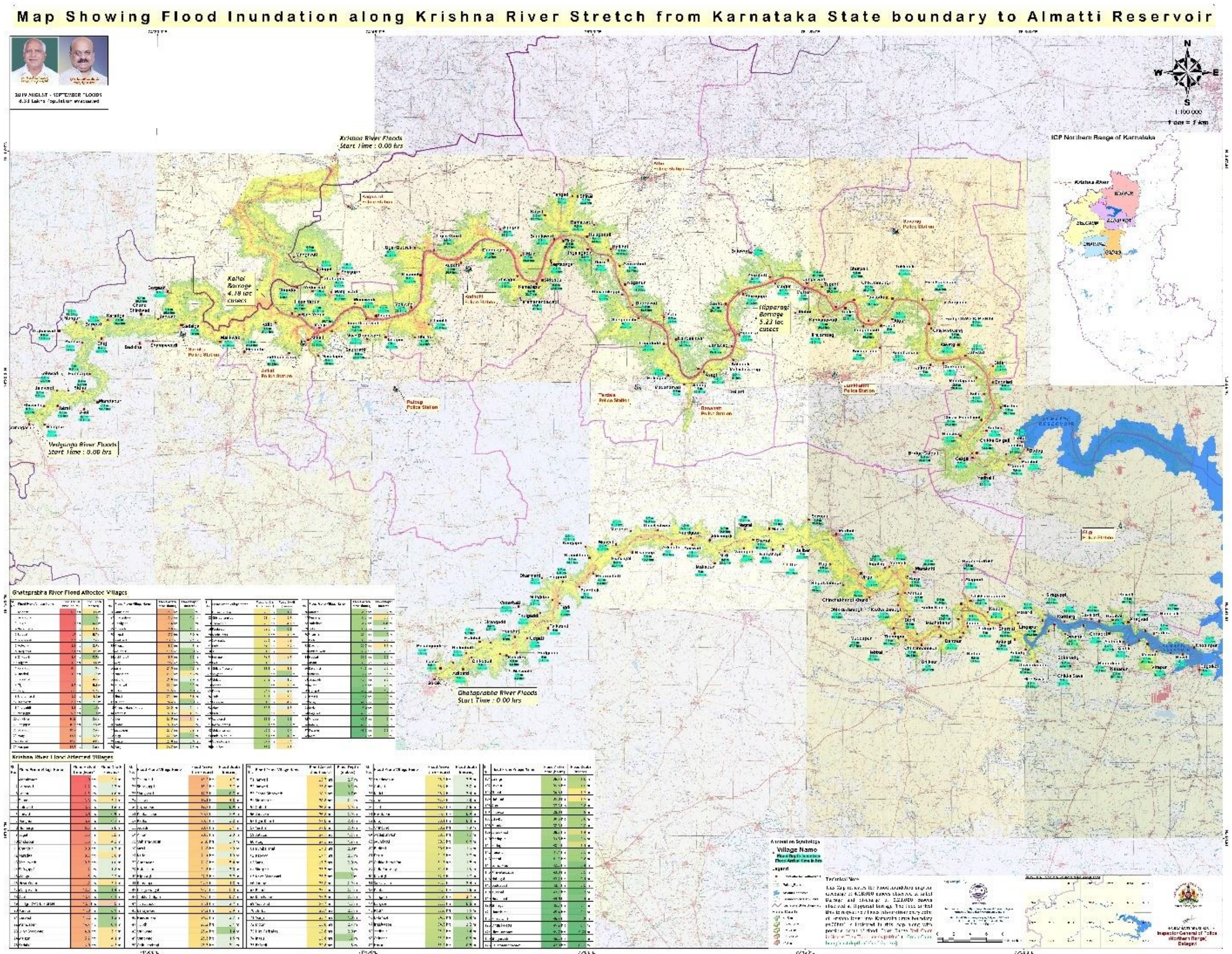


Figure 4.4 : Flood Inundation Map for Krishna Floods during August 2019 for floods near to 5lacs cusecs (Scenario-II)

4.5 Flood Affected Villages

Table 4.5: Flood affected villages during August 2019 for Krishna River floods near to 2lacs cusecs (Scenario-I)

Sl. No.	Flood Prone Village Name	Flood Depth (metres)		Flood Arrival time (hours)	
1	Babalad	1.5	m	0.0	hrs
2	Badagi	1.8	m	0.0	hrs
3	Bidari	3.0	m	0.0	hrs
4	Bridge DWD-BJP SH34	8.5	m	0.0	hrs
5	Bridge Galgali	7.0	m	0.0	hrs
6	Budihal	2.4	m	0.0	hrs
7	Chikka Hanchinal	3.0	m	0.0	hrs
8	Chingundi	2.1	m	0.0	hrs
9	Galgali	1.5	m	0.0	hrs
10	Hosur	2.7	m	0.0	hrs
11	Jambgi	1.8	m	0.0	hrs
12	Janwad	3.0	m	0.0	hrs
13	Kavatgi	2.0	m	0.0	hrs
14	Kolur	2.4	m	0.0	hrs
15	Mundaganur	3.6	m	0.0	hrs
16	Shirbur	3.3	m	0.0	hrs
17	Yadhalli	0.9	m	0.0	hrs
18	Jainwadi	1.7	m	3.3	hrs
19	Sidnal	2.5	m	4.6	hrs
20	Jatrat	0.8	m	4.8	hrs
21	Madalmatti	1.8	m	8.4	hrs
22	Hunnargi	1.2	m	9.4	hrs
23	Shahapur	3.0	m	10.0	hrs
24	Jugal	2.3	m	10.1	hrs
25	Kunnur	1.0	m	11.5	hrs
26	Barwad	2.4	m	11.5	hrs
27	Karadga	2.9	m	13.5	hrs
28	Chandur	0.4	m	18.5	hrs
29	Shirguppi	0.5	m	20.8	hrs
30	Sadalgi	3.0	m	21.3	hrs
31	June Diggewadi	3.7	m	23.3	hrs
32	Mangur	0.4	m	26.0	hrs
33	Saundatti	2.1	m	28.2	hrs
34	Shiragur	3.8	m	31.5	hrs
35	Gundawad	4.0	m	32.1	hrs
36	Hippargi	3.5	m	32.3	hrs
37	Chik Padsalagi	1.6	m	32.3	hrs
38	Kadkol	2.4	m	32.4	hrs
39	Hosa Yedur	1.4	m	32.5	hrs
40	Shiraguppi	3.2	m	33.2	hrs
41	Kusanal	2.7	m	33.2	hrs
42	Kemalapur	3.5	m	33.3	hrs
43	Hire Padsalagi	1.9	m	33.5	hrs
44	Malikwad	0.9	m	34.0	hrs
45	Kankanawadi	2.4	m	34.3	hrs
46	Bhoj	0.1	m	34.8	hrs
47	Banajawad	2.7	m	36.9	hrs
48	Ingali	1.4	m	37.3	hrs
49	Ugar Budruk	2.3	m	37.5	hrs
50	Shirahatti	2.2	m	38.3	hrs
51	Satti	2.8	m	38.5	hrs
52	Manewadi	0.9	m	41.0	hrs
53	Chik Jambagi	1.7	m	41.6	hrs
54	Kallol	0.6	m	42.0	hrs
55	Shegunashi	2.1	m	43.0	hrs
56	Takkod	1.5	m	43.0	hrs
57	Tupchi	1.5	m	43.3	hrs
58	Savadi	2.1	m	43.3	hrs
59	Takkalaki	1.3	m	44.7	hrs
60	Tirth	1.7	m	45.7	hrs
61	Mahishawadigi	1.6	m	46.3	hrs
62	Shurpali	1.2	m	46.5	hrs
63	Ugar Khurd	1.1	m	47.4	hrs
64	Kittur	1.3	m	47.5	hrs
65	Muttur	1.3	m	48.2	hrs
66	Ankali	0.6	m	48.7	hrs
67	Jalalpur	0.6	m	49.0	hrs
68	Tamadaddi	1.6	m	49.0	hrs
69	Maigur	1.1	m	50.5	hrs
70	Kudchi	0.8	m	52.9	hrs
71	Tangadi	1.9	m	53.0	hrs
72	Darur	1.4	m	53.0	hrs
73	Hale Yedur	0.3	m	53.0	hrs
74	Saptasagar	1.1	m	53.3	hrs
75	Kulahalli	1.0	m	54.9	hrs
76	Chinchli	0.6	m	55.6	hrs
77	Halingali	1.0	m	55.9	hrs

Sl. No.	Flood Prone Village Name	Flood Depth (metres)		Flood Arrival time (hours)	
78	Lingadakatti	0.7	m	56.0	hrs
79	Hire Jambagi	0.7	m	56.2	hrs
80	Manjri	0.2	m	57.5	hrs
81	Hulagabali	0.9	m	57.7	hrs
82	Ingalagaon	0.9	m	57.8	hrs
83	Janawad	0.8	m	57.8	hrs
84	Junjarwad	0.7	m	57.8	hrs
85	Katral	0.7	m	59.4	hrs
86	Naganur	0.6	m	61.5	hrs
87	Siddapur	0.4	m	61.8	hrs

Sl. No.	Flood Prone Village Name	Flood Depth (metres)		Flood Arrival time (hours)	
88	Asagi	0.6	m	62.0	hrs
89	Hallihal	0.6	m	62.8	hrs
90	Khavatakoppa	0.5	m	63.3	hrs
91	Kunchanur	0.3	m	63.3	hrs
92	Doddavad	0.3	m	66.0	hrs
93	Rabkavi	0.1	m	67.3	hrs
94	Avarakhod	0.1	m	68.0	hrs
95	Bhiradi	0.1	m	68.8	hrs
96	Molawad	0.0	m	68.8	hrs

Table 4.6 : Flood affected villages during August 2019 for Krishna River floods near to 5lacs cusecs (Scenario-II)

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
1	Madalmatti	1.0	hrs	3.3	m
2	Jainwadi	2.2	hrs	2.7	m
3	Jatrat	2.5	hrs	1.6	m
4	Sidnal	3.3	hrs	3.4	m
5	Bolewadi	3.3	hrs	1.6	m
6	Bhivashi	3.8	hrs	0.9	m
7	Nangnur	5.9	hrs	0.8	m
8	Hunnargi	6.5	hrs	2.0	m
9	Jugal	7.3	hrs	3.5	m
10	Shahapur	7.5	hrs	4.2	m
11	Chandur	9.0	hrs	1.7	m
12	Karadga	10.3	hrs	3.6	m
13	Yedurwadi	10.5	hrs	1.6	m
14	Shirguppi	11.2	hrs	1.8	m
15	Mangur	11.5	hrs	2.2	m
16	Hosa Yedur	11.7	hrs	3.1	m
17	Manjriwadi	12.7	hrs	1.4	m
18	Akol	13.3	hrs	0.1	m
19	Bridge DWD-BJP SH34	13.5	hrs	8.5	m
20	Kunnur	14.0	hrs	0.9	m
21	Barwad	14.2	hrs	1.2	m
22	Mamdapur	14.7	hrs	0.1	m
23	June Diggewadi	14.8	hrs	5.3	m
24	Maigur	15.2	hrs	4.1	m
25	Sadalgi	16.0	hrs	4.5	m
26	Takkalaki	16.2	hrs	4.7	m
27	Shiraguppi	16.4	hrs	3.7	m
28	Mangavati	17.7	hrs	0.3	m

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
29	Takkod	18.1	hrs	4.0	m
30	Gajbarwadi	19.8	hrs	0.9	m
31	Kankanawadi	20.3	hrs	2.9	m
32	Kadkol	20.3	hrs	3.0	m
33	Savadi	20.7	hrs	3.1	m
34	Ankali	20.8	hrs	2.3	m
35	Mahishawadigi	21.0	hrs	2.9	m
36	Satti	21.0	hrs	3.9	m
37	Kallol	21.1	hrs	1.9	m
38	Gundawad	21.8	hrs	5.4	m
39	Hale Yedur	21.8	hrs	2.0	m
40	Hippargi	22.5	hrs	2.7	m
41	Kemalapur	22.7	hrs	4.8	m
42	Bridge Galgali	23.5	hrs	5.3	m
43	Chikka Galgali	23.5	hrs	5.2	m
44	Tamadaddi	24.1	hrs	2.7	m
45	Banajawad	24.2	hrs	3.9	m
46	Nandeshwar	24.3	hrs	2.7	m
47	Tupchi	25.2	hrs	2.1	m
48	Malikwad	25.4	hrs	1.4	m
49	Manewadi	25.5	hrs	1.5	m
50	Chik Jambagi	25.7	hrs	2.1	m
51	Janwad	25.7	hrs	2.7	m
52	Janwad	25.8	hrs	0.9	m
53	Chand Shirdwadi	26.3	hrs	0.7	m
54	Shirahatti	26.8	hrs	2.1	m
55	Gulbal	26.8	hrs	3.9	m
56	Janawad	26.8	hrs	2.0	m
57	Ugar Khurd	27.0	hrs	2.8	m

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
58	Muttur	27.0	hrs	2.0	m
59	Jalalpur	27.1	hrs	1.6	m
60	Asagi	27.3	hrs	1.9	m
61	Kumbarahal	27.3	hrs	2.0	m
62	Rabkavi	27.5	hrs	2.5	m
63	Sanal	27.7	hrs	2.0	m
64	Shurpali	27.7	hrs	1.8	m
65	Nave Diggewari	27.7	hrs	1.3	m
66	Jambgi	27.8	hrs	2.9	m
67	Bidari	28.1	hrs	2.4	m
68	Kunchanur	28.2	hrs	2.2	m
69	Molawad	28.7	hrs	1.7	m
70	Shirbur	28.7	hrs	2.3	m
71	Manjri	28.7	hrs	1.0	m
72	Kittur	28.8	hrs	2.7	m
73	Hire Padsalagi	28.8	hrs	2.0	m
74	Ingali	28.8	hrs	1.2	m
75	Bhiradi	28.8	hrs	1.8	m
76	Mundaganur	28.8	hrs	2.8	m
77	Galgali	28.9	hrs	2.2	m
78	Kudchi	28.9	hrs	2.4	m
79	Albal	29.3	hrs	1.8	m
80	Tirth	29.3	hrs	2.8	m
81	Nasalapur	30.0	hrs	0.9	m
82	Bhoj	30.1	hrs	0.4	m
83	Chingundi	30.2	hrs	1.9	m
84	Siddapurwadi	30.3	hrs	1.0	m
85	Saundatti	30.3	hrs	0.8	m
86	Budihal	30.9	hrs	1.6	m
87	Darur	31.3	hrs	2.7	m
88	Chikka Hanchinal	31.5	hrs	1.8	m
89	Chik Padsalagi	31.8	hrs	1.6	m
90	Kavatgi	32.3	hrs	1.7	m
91	Saptasagar	32.5	hrs	2.4	m
92	Kanbur	32.8	hrs	1.6	m

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
93	Tangadi	33.0	hrs	3.7	m
94	Borgaon	33.3	hrs	0.5	m
95	Kolur	33.6	hrs	1.6	m
96	Eksambe	34.3	hrs	0.4	m
97	Ingalagaon	34.5	hrs	2.2	m
98	Yadhalli	35.2	hrs	1.4	m
99	Chinchli	35.3	hrs	0.8	m
100	Hosur	36.2	hrs	0.5	m
101	Asangi	36.7	hrs	1.0	m
102	Jaknur	36.8	hrs	1.0	m
103	Shinal	36.8	hrs	1.7	m
104	Hallihal	36.8	hrs	1.9	m
105	Algur	37.3	hrs	0.8	m
106	Balawad	38.0	hrs	0.9	m
107	Ainapur	38.3	hrs	0.8	m
108	Babalad	38.5	hrs	0.8	m
109	Avarakhod	38.7	hrs	1.4	m
110	Siddapur	39.5	hrs	0.9	m
111	Badagi	40.5	hrs	1.4	m
112	Naganur	41.1	hrs	0.8	m
113	Katral	41.3	hrs	0.8	m
114	Junjarwad	42.7	hrs	0.4	m
115	Khavatakoppa	43.0	hrs	0.5	m
116	Halingali	43.2	hrs	0.4	m
117	Doddavad	43.4	hrs	0.5	m
118	Kusanal	43.7	hrs	0.2	m
119	Hulagabali	44.0	hrs	0.4	m
120	Shiragur	45.3	hrs	0.1	m
121	Ugar Budruk	45.4	hrs	0.1	m
122	Ramawadi	45.8	hrs	0.2	m
123	Lingadakatti	46.2	hrs	0.1	m
124	Hire Jambagi	46.7	hrs	0.04	m
125	Shegunashi	46.7	hrs	0.1	m
126	Paramanandawadi	47.0	hrs	0.01	m

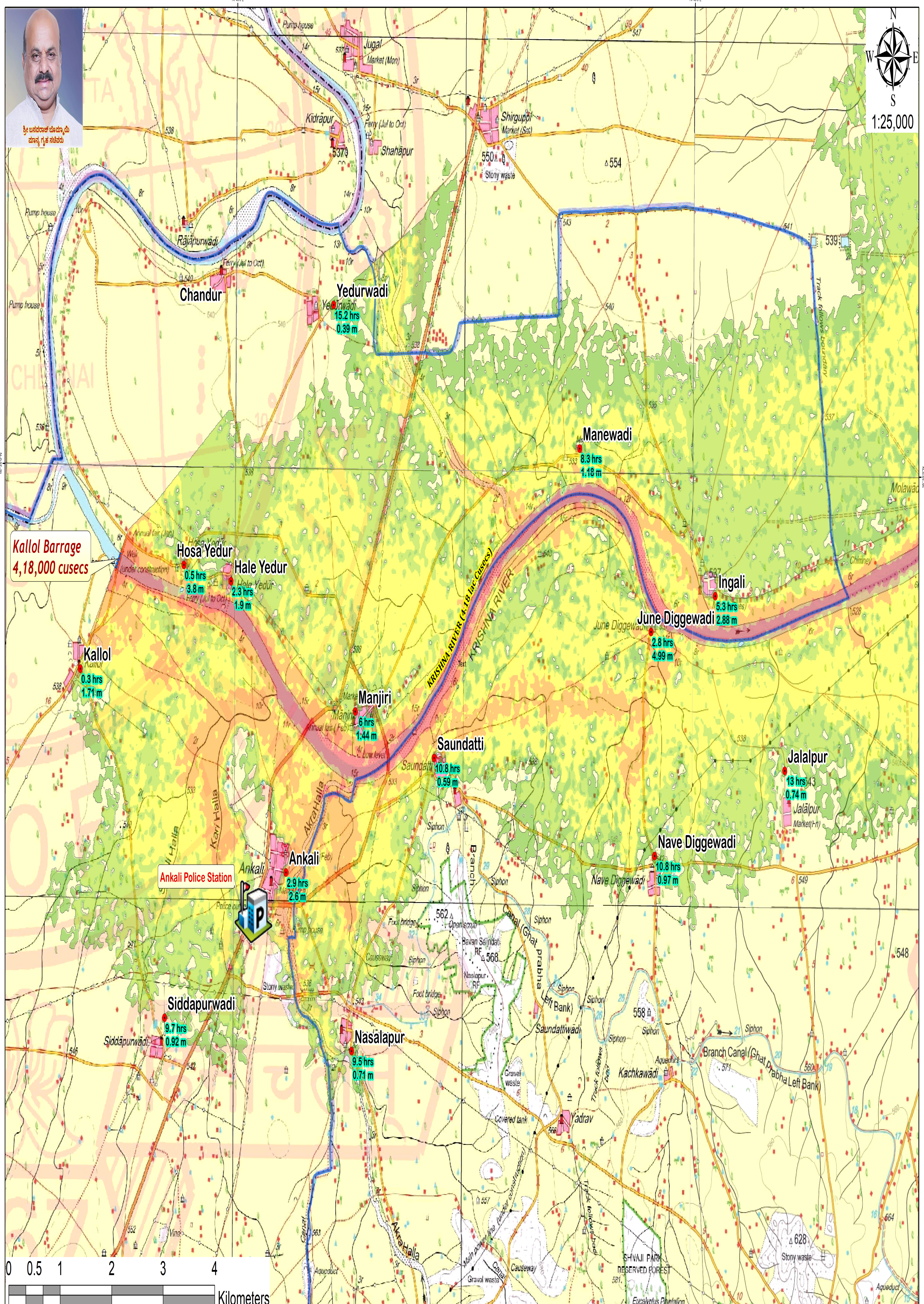
Table 4.7: Flood affected villages during August 2019 for Ghataprabha River floods near to 2lacs cusecs

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
1	Adibatti	0.8	hrs	3.9	m
2	Basaligundi	1.3	hrs	1.1	m
3	Lolsur	1.3	hrs	0.6	m
4	Nallanhatti	1.6	hrs	3.3	m
5	Balobal	1.7	hrs	5.7	m
6	Birangaddi	2.7	hrs	2.6	m
7	Melvanki	3.3	hrs	2.9	m

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
8	Hadginhal	3.4	hrs	4.0	m
9	Chikdauli	3.9	hrs	0.9	m
10	Udgatti	4.2	hrs	3.6	m
11	Kalarkop	4.3	hrs	1.9	m
12	Hunshal	5.0	hrs	1.7	m
13	Talkatnal	5.3	hrs	4.0	m
14	Tigdi	5.8	hrs	5.5	m

Sl. No.	Flood Prone Village Name	Flood Arrival time (hours)		Flood Depth (metres)	
15	Patgundi	6.8	hrs	5.2	m
16	Bhairanhatti	8.3	hrs	4.8	m
17	Dharmatti	8.5	hrs	2.1	m
18	Phulgaddi	8.8	hrs	1.1	m
19	Musguppi	9.7	hrs	1.3	m
20	Sundholi	10.2	hrs	2.0	m
21	Rangapur	10.2	hrs	2.9	m
22	Bisankop	12.2	hrs	2.6	m
23	Munyal	12.3	hrs	2.2	m
24	Arlimatti	12.6	hrs	4.0	m
25	Marapur	12.7	hrs	2.6	m
26	Kamaldinni	14.1	hrs	1.1	m
27	Dhavleshwar	16.3	hrs	1.2	m
28	Nandgaon	16.8	hrs	1.3	m
29	Aurwadi	16.8	hrs	1.3	m
30	Nagral	17.2	hrs	3.0	m
31	Vantigod	18.2	hrs	2.1	m
32	Chenal	18.3	hrs	1.9	m
33	Mallapur	19.6	hrs	1.0	m
34	Akkimardi	19.9	hrs	0.7	m
35	Mirji	20.2	hrs	0.9	m
36	Malali	21.0	hrs	1.3	m
37	Bannidinni	21.1	hrs	4.3	m
38	Mudhol	21.8	hrs	2.4	m
39	Hunshyal	22.4	hrs	0.3	m
40	Uttur	22.5	hrs	1.0	m
41	Jirgal	23.1	hrs	3.8	m
42	Jaliber	24.4	hrs	1.0	m
43	Chinchakhandi Khurd	26.0	hrs	2.1	m
44	Antapur	27.0	hrs	4.1	m
45	Bidri	27.0	hrs	6.4	m
46	Yadhalli	27.0	hrs	3.5	m
47	Muddapur	27.7	hrs	5.9	m
48	Rugi	27.7	hrs	0.9	m
49	Ingalagi	27.8	hrs	2.6	m
50	Bargi	28.7	hrs	2.5	m
51	Gulgal Jambgi	29.0	hrs	1.2	m
52	Chitrabhanukot	29.4	hrs	5.7	m
53	Timmapur	29.5	hrs	4.1	m
54	Ranjanagi	29.5	hrs	0.6	m
55	Machakanur	30.5	hrs	4.6	m
56	Sokanadgi	30.6	hrs	5.2	m
57	Badnur	31.0	hrs	5.9	m
58	Junnur	31.6	hrs	5.3	m
59	Bantnur	31.7	hrs	4.6	m
60	Budni Khurd	31.9	hrs	2.5	m
61	Chikka Alagundi	33.8	hrs	3.3	m
62	Sorgoan	33.8	hrs	0.2	m
63	Chikkur	34.2	hrs	2.0	m
64	Shardal	34.6	hrs	3.4	m
65	Koppa	34.7	hrs	2.9	m
66	Yadhalli	34.7	hrs	3.4	m
67	Lingapur	34.8	hrs	4.7	m
68	Alagundi	35.8	hrs	1.8	m
69	Budihal	35.9	hrs	3.6	m
70	Marakatti	36.3	hrs	0.6	m
71	Kasba Jambgi	36.4	hrs	0.7	m
72	Chikka Jambgi	36.6	hrs	0.7	m
73	Budni Budrukh	37.1	hrs	1.4	m
74	Govindkoppa	37.9	hrs	3.4	m
75	Hire Savsi	37.9	hrs	3.7	m
76	Katarki	38.0	hrs	1.7	m
77	Kundargi	38.5	hrs	3.9	m
78	Vaderhatti	38.7	hrs	0.05	m
79	Ankalgi	38.8	hrs	1.5	m
80	Udagatti	39.1	hrs	1.0	m
81	Kadampur	39.2	hrs	2.7	m
82	Devanal	39.7	hrs	3.3	m
83	Chikka Savsi	39.7	hrs	2.3	m
84	Hebbal	39.7	hrs	0.5	m
85	Andili	39.9	hrs	2.7	m
86	Bavalatti	41.3	hrs	2.3	m
87	Chhabbi	42.2	hrs	1.8	m
88	Anagvadi	42.4	hrs	2.0	m
89	Murnal	42.5	hrs	2.3	m
90	Honaralli	44.7	hrs	1.3	m
91	Haveli	44.7	hrs	1.3	m
92	Siraguppi	44.8	hrs	0.4	m
93	Sorkop	45.0	hrs	1.1	m
94	Bagalkot	45.3	hrs	0.9	m
95	Virapur	45.7	hrs	1.2	m
96	Kaladgi	45.9	hrs	0.2	m
97	Kesanur	46.5	hrs	0.3	m
98	Kovalli	46.7	hrs	0.1	m

Map Showing Flood Inundation along Krishna River Stretch under Ankali Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 4,18,000 cusecs observed at Kallol Barrage at time set at 0:00 hrs. The flood arrival time to respective villages in hours from Kallol Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

KARNATAKA STATE POLICE

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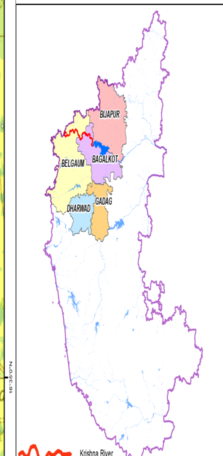
Belagavi



Legend

- Police Stations
- Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

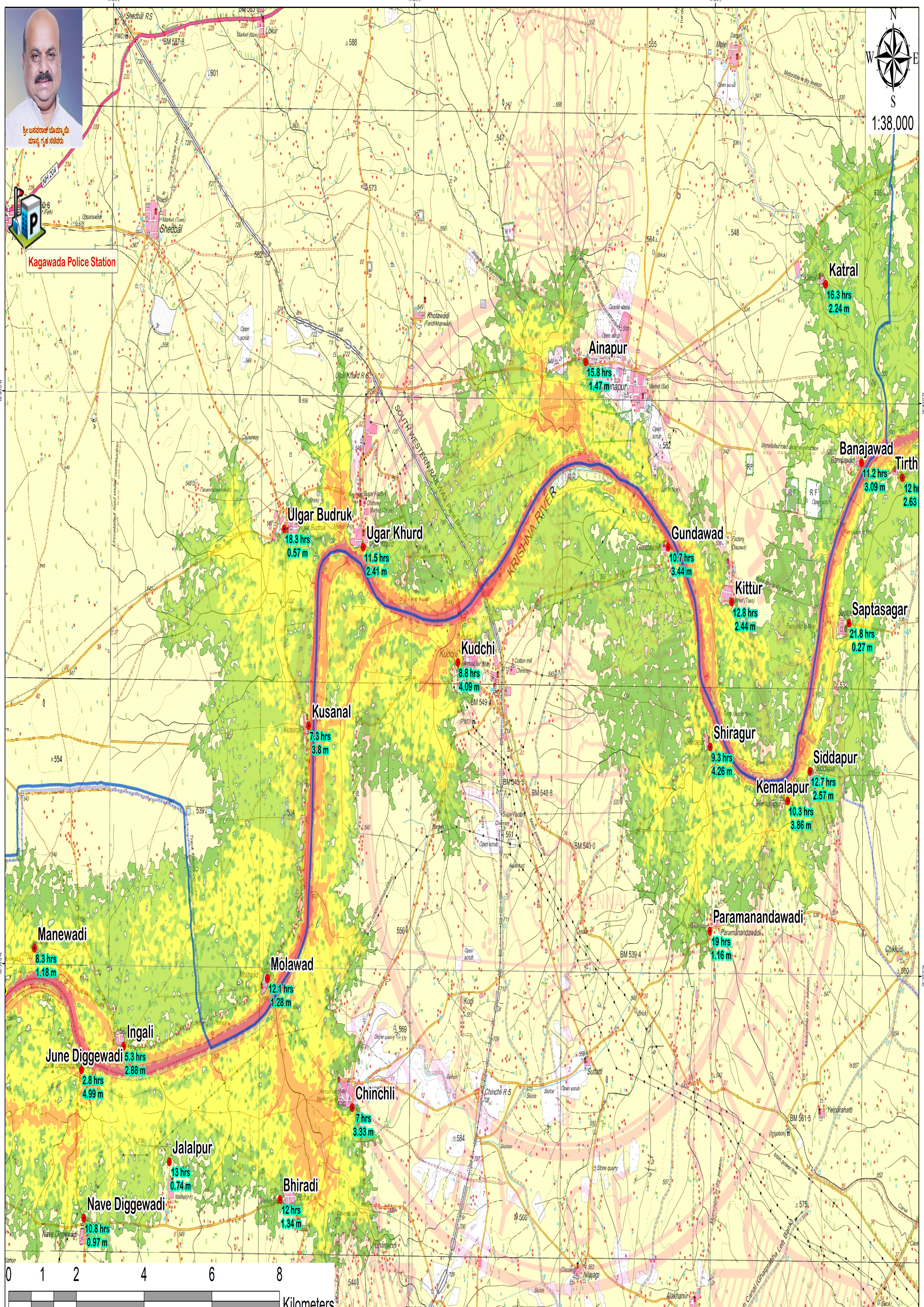
Map Compiled by

Hard Rock Regional Centre,
National Institute of Hydrology, Belagavi
Ministry of Jal Shakti, Government of India

Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Kallol	0.25	1.71
2	Hosa Yedur	0.50	3.80
3	Hale Yedur	2.25	1.90
4	Ankali	2.94	2.60
5	Ingali	5.25	2.88
6	Manjiri	6.05	1.44
7	Manewadi	8.25	1.18
8	Siddapurwadi	9.73	0.92
9	Yedurwadi	15.23	0.39

Map Showing Flood Inundation along Krishna River Stretch under Kagawada Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 4,18,000 cusecs observed at Kallol Barrage at time set at 0:00 hrs. The flood arrival time to respective villages in hours from Kallol Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

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Inspector General of Police
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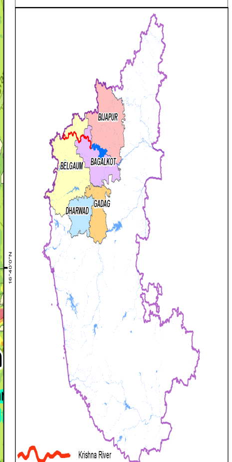

Legend

Police Stations

Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

Map Compiled by

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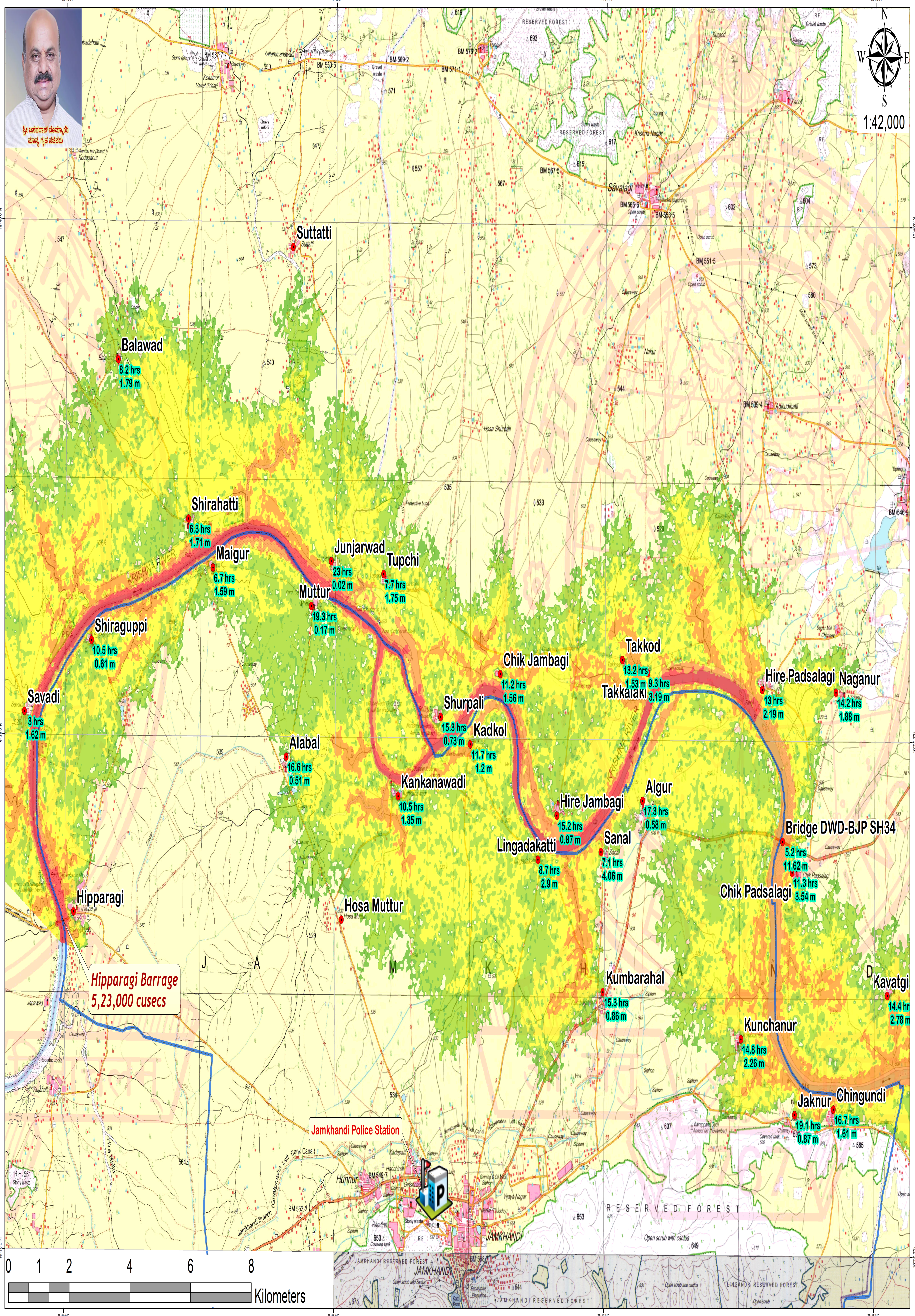
Hard Rock Regional Centre,
National Institute of Hydrology, Belagavi
Ministry of Jal Shakti, Government of India

NOVEMBER 2020

Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Kusanal	7.33	3.80
2	Banajawad	11.23	3.09
3	Ugar Khurd	11.50	2.41
4	Molawad	12.06	1.28
5	Kittur	12.75	2.44
6	Ainapur	15.75	1.47
7	Katral	16.25	2.24
8	Ulgar Budruk	18.25	0.57

Map Showing Flood Inundation along Krishna River Stretch under Jamkhandi Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 5,23,000 cusecs observed at Hipparagi Barrage at time set at 0:00 hrs. The flood arrival time to respective villages in hours from Hipparagi Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

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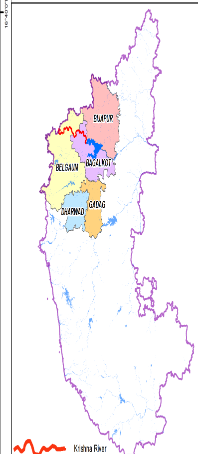


Legend

- Police Stations
- Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

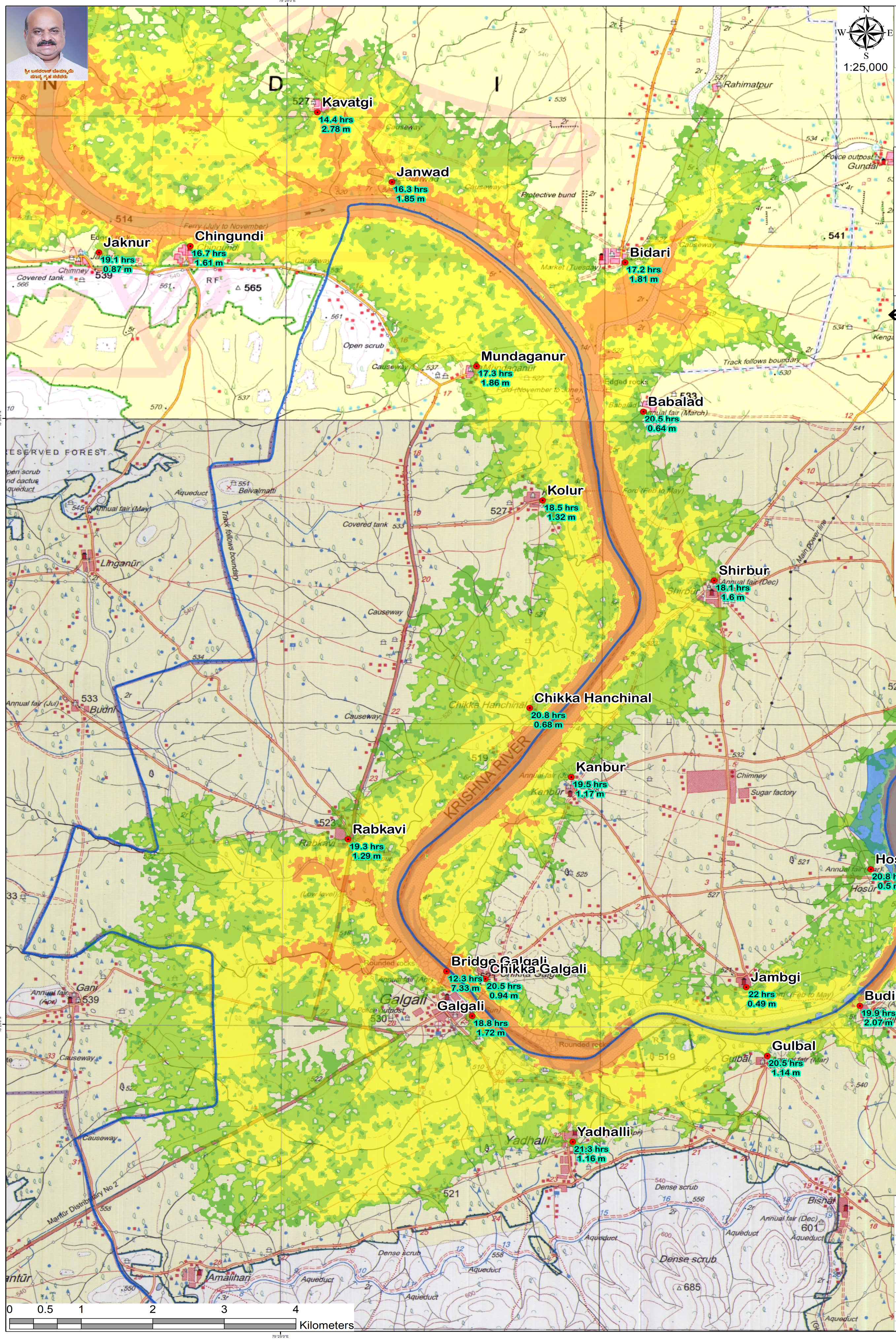
Map Compiled by

Hard Rock Regional Centre,
National Institute of Hydrology, Belagavi
Ministry of Jal Shakti, Government of India

Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Maigur	6.67	1.59
2	Sanal	7.13	4.06
3	Lingadakatti	8.67	2.90
4	Kankanawadi	10.50	1.35
5	Shiraguppi	10.52	0.61
6	Kadkol	11.67	1.20
7	Kunchanur	14.83	2.26
8	Kumbarahal	15.33	0.86
9	Alabal	16.55	0.51
10	Chingundi	16.68	1.61
11	Algur	17.33	0.58
12	Jaknur	19.11	0.87
13	Muttur	19.32	0.17

Map Showing Flood Inundation along Krishna River Stretch under Biligi Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 5,23,000 cusecs observed at Hipparagi Barrage and 2,14,742 cusecs observed in Ghataprabha River at time set to 0:00 hrs. The flood arrival time to respective villages in hours from Hipparagi Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

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Bilgi PS Jurisdiction

Legend

- Police Stations
- Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

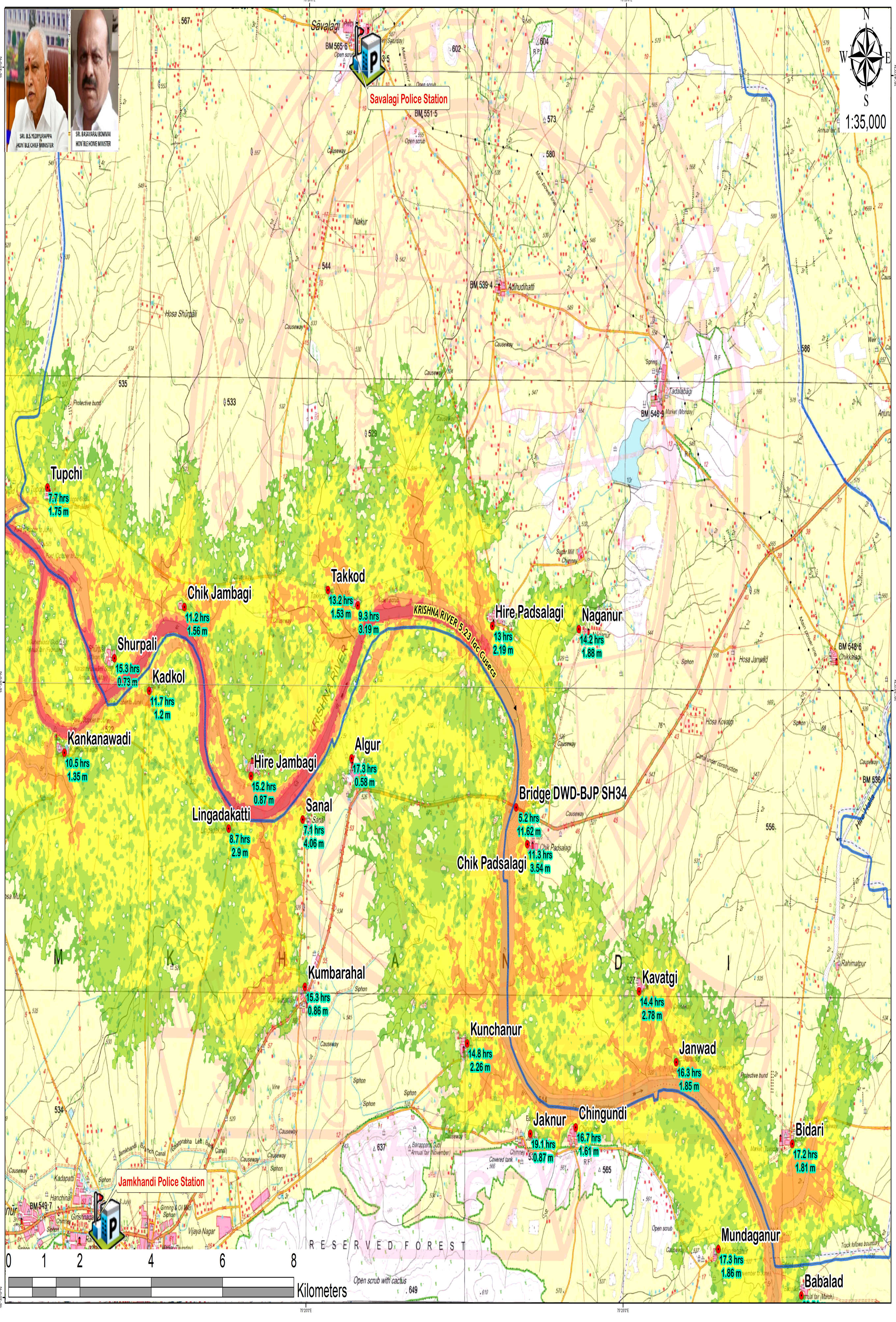
Map Compiled by

Hard Rock Regional Centre, National Institute of Hydrology, Belagavi
Ministry of Jal Shakti, Government of India

Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Bridge Galgali	12.33	7.33
2	Mundaganur	17.33	1.86
3	Kolur	18.50	1.32
4	Galgali	18.83	1.72
5	Rabkavi	19.34	1.29
6	Budihal	19.86	2.07
7	Gulbal	20.47	1.14
8	Chikka Hanchin	20.79	0.68
9	Badagi	20.94	1.66
10	Yadhalli	21.27	1.16

Map Showing Flood Inundation along Krishna River Stretch under Savalagi Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 5,23,000 cusecs observed at Hipparagi Barrage at time set at 0:00 hrs. The flood arrival time to respective villages in hours from Hipparagi Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

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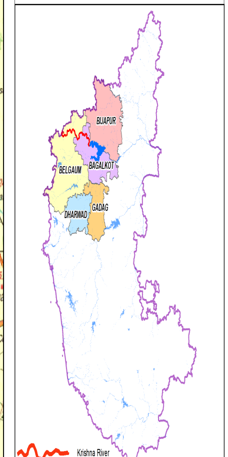

Legend

- Police Stations
- Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

Map Compiled by

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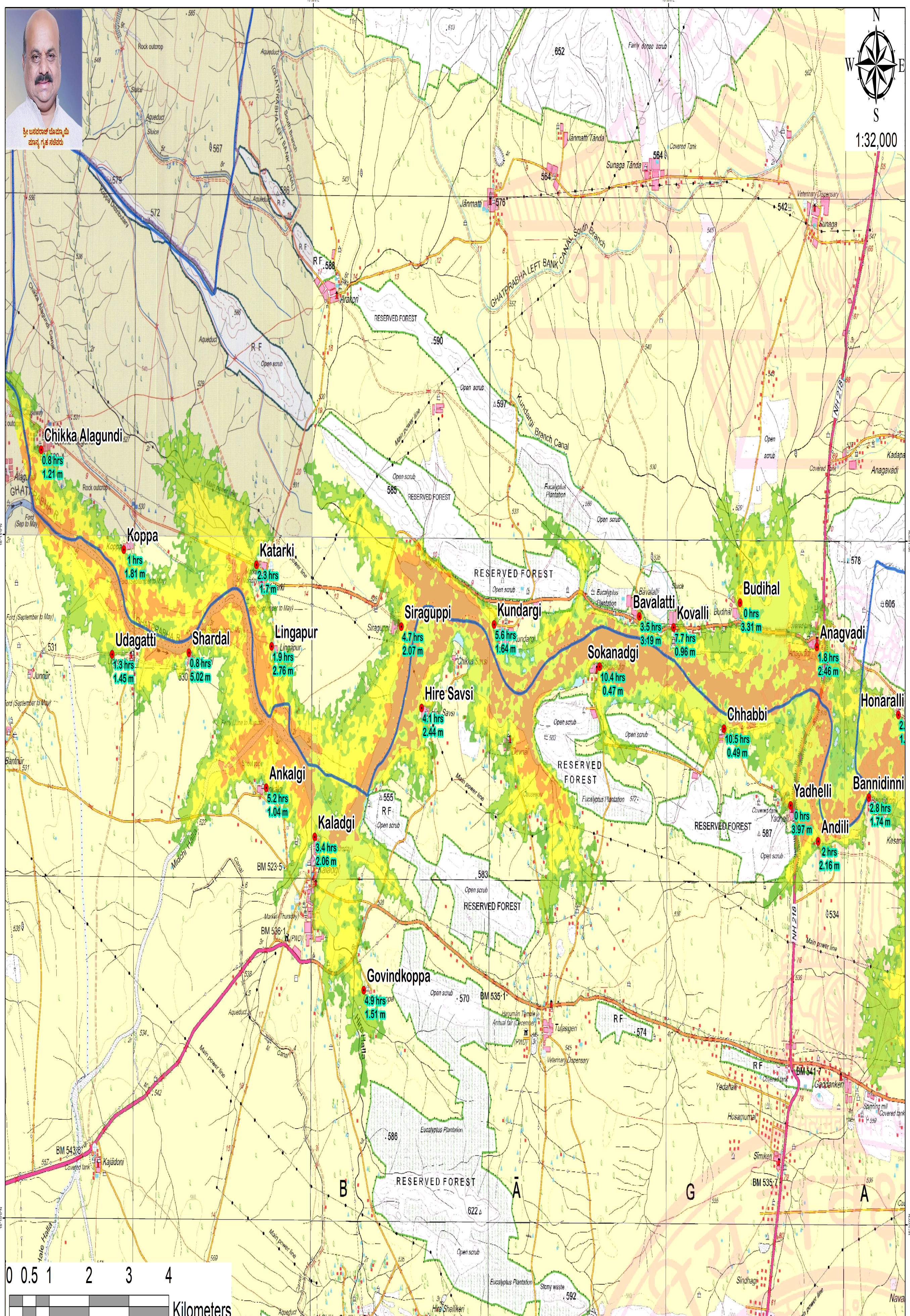
Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Bridge DWD-BJP SH34	5.22	11.62
2	Tupchi	7.67	1.75
3	Takkalaki	9.26	3.19
4	Chik Jambagi	11.24	1.56
5	Chik Padsalagi	11.33	3.54
6	Hire Padsalagi	12.99	2.19
7	Takkod	13.17	1.53
8	Naganur	14.24	1.88
9	Kavatgi	14.35	2.78
10	Hire Jambagi	15.17	0.87
11	Shurpali	15.35	0.73
12	Janwad	16.35	1.85
13	Bidari	17.17	1.81

Map Showing Flood Inundation along Ghataprabha River Stretch under Bilgi Police Station Jurisdiction



Technical Note:

This Map indicates the Flood inundation map for the discharge of 2,14,742 cusecs observed in Ghataprabha River at time set to 0:00 hrs. The flood arrival time to respective villages in hours from Hipparagi Barrage (0:00hrs) is indicated in this map along with possible depth of flood. Color Range Red Color indicates High Flood levels (>12m) to Green Color being least depth of Flood (<1.5m)

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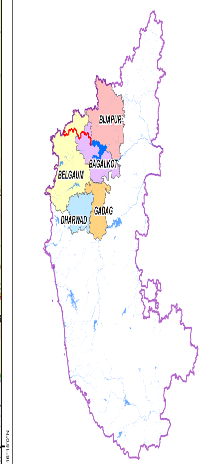

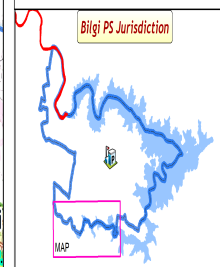

Legend

- Police Stations
- Settlements

Flood Depth

- <1.5 m
- 1.5 - 3 m
- 3 - 6 m
- 6 - 12 m
- 12 - 33 m
- Inundation Boundary

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Ministry of Jal Shakti, Government of India

NOVEMBER 2020

Flood Details

Sl no	Village_Name	Arrival Time (Hrs)	Depth (m)
1	Budihal (near FRL)	0.00	3.31
2	Chikka Alagundi	0.81	1.21
3	Koppa	1.03	1.81
4	Anagvadi	1.81	2.46
5	Lingapur	1.86	2.76
6	Katarki	2.33	1.70
7	Bavalatti	3.50	3.19
8	Siraguppi	4.66	2.07
9	Kundargi	5.58	1.64
10	Kovalli	7.67	0.96

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